Properties of aggregate

Aggregate: a building material connected into a cohesive whole by means of the cement paste, in a manner similar to masonry constructions. Aggregate is at least $\frac{3}{4}$ of the volume of concrete (60-75% of the volume of concrete).

Aggregate was viewed as an inert material dispersed throughout the cement paste largely for economic reasons. However, aggregate is not truly inert and its physical, thermal and sometimes chemical properties influence the performance of concrete.

The properties of aggregate affect concrete properties such as:

- ✓ Durability of concrete.
- ✓ Structural performance of concrete.
- ✓ The obtained strength of concrete.

Q./ Why the use of aggregate in concrete is useful?

A./ because:

(1) Aggregate is cheaper than cement.

(2) Aggregate provides technical advantages such as: higher volume stability and better durability than hydrated cement made alone.

General classification of aggregates:

- The size of aggregate used in concrete ranges from tens mm down to particles less than $\frac{1}{10}\ mm$ in cross-section.
- Sieve No.4 (ASTM) or 5 mm is deciding the fine and coarse aggregate:

  Coarse aggregate: Aggregates predominately retained on the No. 4 (4.75 mm) sieve.

Fine aggregate (sand): Aggregates passing No.4 (4.75 mm) sieve and predominately retained on the No. 200 (75 µm) sieve.

Classification of aggregates:

Aggregates can be divided into several categories according to different criteria:

(1) *Particle size classification:*

gravel > 5 mm

Sand 0.07-5 mm

Silt 0.002-0.06 mm

Clay < 0.002 mm

(2) *Petrological classification:*

- Natural:
  a) Sedimentary.
  b) Metamorphic.
  c) Igneous.

- Artificial:
  a) produced.
  b) by product.

Natural aggregates: have been fragmented by natural processing of weathering and abrasion or artificially by crushing.

- Many properties of aggregates depends upon the properties of the parent rock (rock from which it is obtained) like:
  - Chemical and mineralogical composition.
  - Specific gravity.
  - Hardness.
  - Strength.

- Physical and chemical stability.
- Pore structure.
- Colour
- Petrological character.

(3) Weight classification:

Heavy weight ,normal weight and light weight

(4) Surface texture:

a) glassy.

b) smooth.

c) granular.

d) rough

e) crystalline.

f) honey-combed.

Questions:

Q.1/ What are the properties of the rock which affect the properties of aggregate?

A.1/

1) chemical composition.
2) Specific gravity.
3) Hardness.
4) Strength.
5) Chemical stability.

Q.2/ What are the properties of aggregates which do NOT depend upon the properties of the rock?

A.2/ 1) particle size. 2) Particle shape. 3) Absorption.4) Surface texture

(5) Shape:

Aggregates can be classified according to the shape of their particles:

1- *Roundness aggregates*: roundness described the relative sharpness or angularity of the edges and corners of a particle.

- Roundness is controlled largely by the strength and abrasion resistance of the parent rock and by the amount of wear to which the particle has been subjected.

- In the case of *crushed aggregate*: the particle shape depends not only on the nature of the parent material but also on:

  * The type of crusher.

  *The reduction ratio of the crusher (the ratio of the size of material fed into the crusher to the size of the finished product).

2- *Spherical Aggregates*: having low ratio of surface area to volume. So, they need less water.

3- *Elongated and flaky Aggregates:* these particles are not preferred because they tend to oriented in one plane, with bleeding water and air voids forming underneath.

Flakiness index: the mass of flaky particles expressed as a percentage of the mass of the sample.

Elongation index : the mass of elongated particles expressed as a percentage of the mass of the sample.

Surface texture of aggregates

Surface texture of aggregates affects the bond between the cement paste and the aggregates.

The main effects of surface texture of aggregate on concrete properties are:

1) Water demand of the mix.
2) Workability of the mix.
3) The transition zone (region between the mortar and the coarse aggregates).
4) Strength of concrete.

Factors that govern the classification of surface texture of the aggregate :

1) Hardness of the parent material.
2) Grain size of the parent material.
3) Pore characteristics (porosity) of the parent materials.

Sampling:

Two methods are used for reducing the size of a sample:

a) *Quartering:* (Figure 1)

- The main sample is mixed and in the case of coarse aggregate, dampened in order to avoid segregation.
- The material is heaped into a cone and then turned over to form a new cone. This is repeated twice, the material always being deposited at the apex of the cone so that the fall of particles is evenly distributed round the circumference.
- The final cone is flatted and divided into quarters. One pair of diagonally opposite quarters is discharged, and the remainder forms the sample for testing, or if still too large, can be reduced by further quartering
- Care must be taken to include all fine material in the appropriated quarter.

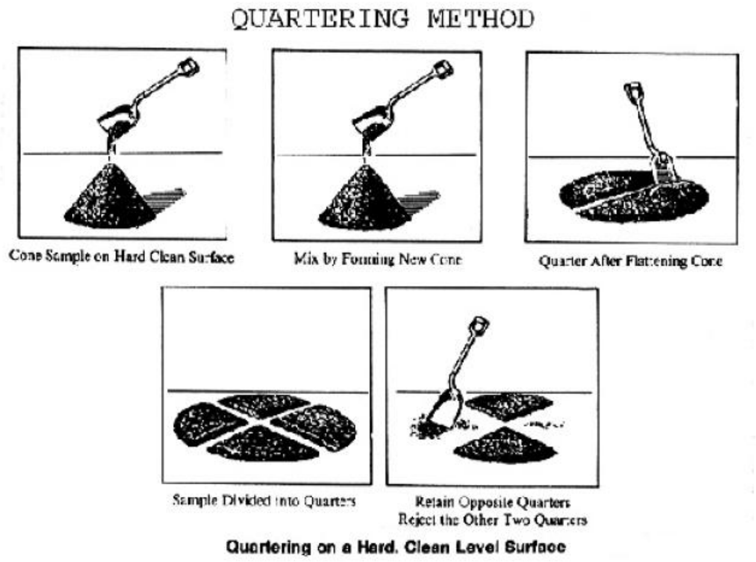

Figure 1:Quartering method

b) ***Riffling:*** according B.S. 812 part 102: 1989.

- The sample is spilt into halves using a riffler (see Figure 2).
- A riffler: is a box with a number of parallel vertical divisions, alternate ones discharging to the left and to the right.
- The sample is discharged into the riffler over its full width, and the two halves are collected in two boxes at the bottom of the chutes on each side.
- One half is discharged, and riffling of the other half is repeated until the sample is reduced to the desired size,

Note: **Riffling gives less variable results than quartering**.

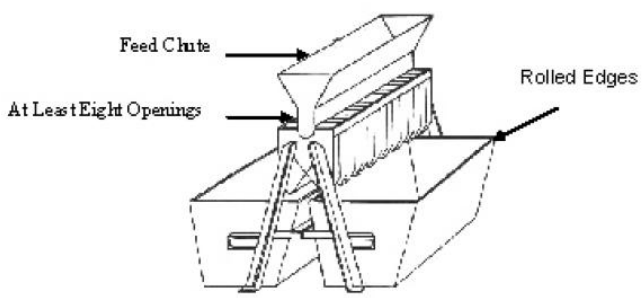

Figure 2: Riffling method

Bond of aggregate

- Bond between aggregate and cement paste is an important factor in the strength of concrete, especially the flexural strength.
- The surface texture (the roughness of the surface of the aggregate) make a good interlocking between the aggregate and the hydrated cement paste.
- Bond is also affected by physical and chemical properties of aggregates, which related to its mineralogical and chemical composition and to the electrostatic condition of the particle surface.
- Bond strength increases with the age of concrete.

Strength of aggregate

The compressive strength of concrete cannot exceed that of the major part of the aggregate contained therein.

The highest value recorded for the crushing strength of aggregate is 530 MPa.

The strength and elasticity of aggregates depend upon:

* aggregate chemical composition.
* aggregate texture.
*aggregate microstructure.

Other mechanical properties of aggregate

Toughness: the resistance of a sample of rock to failure by impact.

Hardness or resistance to wear: is an important property of concrete used in pavements and floor surfaces subjected to heavy traffic.

The aggregate abrasion: the loss as a percentage in mass due to forces of abrasion so that a high value denotes a low abrasion resistance to abrasion.

Specific gravity

It is used to calculate the amount of aggregates required for specific volume of concrete. The aggregate contains:

*permeable pores.
*impermeable pores.

Thus, because of the presence of such pores, the actual volume of the aggregate is less than the apparent volume cause the latter contains pores filled with air.

Absolute or true specific gravity : refers to the volume of the solid material excluding all pores (open and closed pores).

or can be defined as: the ratio of the mass of the solid, referred to vacuum, to the mass of an equal volume of gas-free distilled water, both taken at a stated temperature.

***Apparent specific gravity*: ** the ratio of the mass of the aggregate dried in an oven at 100º C to 110ºC for 24 hrs to the mass of water occupying a volume equal to that of the solid including the impermeable pores.

The apparent specific gravity = $\frac{D}{B-A+D} = \frac{D}{B-(A-D)}$

where:
D: the mass of the oven-dried sample.
B: the mass of the vessel full of water.
A: the mass of the vessel with sample and topped up with water.

The apparent specific gravity of aggregate depends on:

(1) The specific gravity of the mineral of which the aggregate is composed.

(2) The grading of aggregates.

(3) The moisture content of aggregates.

(4) The amount of voids found in aggregates.

***Gross apparent specific gravity*:** is an important for calculation of yield of concrete or the quantity of aggregate required for a given volume of concrete.

Calculations with reference to concrete based on the *saturated and surface dry condition* of the aggregate because the water contained in all the pores in the aggregate does not take part in the chemical reactions.

If a sample of the saturated and surface dry aggregates has a mass C, then:

Gross apparent *specific gravity* = $\frac{C}{B-A+C}$

Bulk density

Aggregate is to be actually batched by volume it is necessary to know the mass of aggregate that would fill a container of unit volume. This is known as the *bulk density* of aggregate, and this density is used to convert quantities by mass to quantities by volume.

Bulk density of aggregate depends on:

1) The size distribution and the shape of particles.
2) Type of grading of aggregates:
   a) *gap grading* which means that some sizes are omitted.
   b) *One size grading*: particles all of one size can be packed to a limited extent.
   c) *Continuous grading*: small particles can filled the voids between the large ones. So, increasing the bulk density of the packed material.

3) The shape of the particles greatly affects the closeness of packing that can be achieved,
4) Degree of packing (degree of compaction):

   For coarse aggregate of given specific gravity: a high bulk density means that there are fewer voids to be filled by fine aggregate and cement, and the bulk density test was at one time used as a basis of proportioning of mixes.

Porosity and absorption of aggregate

The presence of internal pores in the aggregate particles was mentioned in connection with the specific gravity of aggregate, and indeed the characteristics of these pores are very important in the study of its properties.

The porosity of aggregate, its permeability, and absorption influence such properties of aggregate as:

* bond between aggregate and the hydrated cement paste.
*the resistance of concrete to freezing and thawing.
* aggregate chemical stability.
*aggregate resistance to abrasion.

Note: pores smaller than 4 μm are of special interest as they are generally believed to affect the durability of aggregates subjected to alternating freezing and thawing.

The water absorption of aggregate is the ratio of the increase in mass to the mass of the dry sample, express as a percentage.

The absorption of aggregate is determined by measuring the increase in mass of an oven-dried sample when immersed in water for 24 hrs (the surface water being removed). BS 812:Part 2:1975.

Moisture content of aggregate

- ✓ If no water movement into the aggregate is to take place, the pores must be full of water (the aggregate must be in a saturated condition).
- ✓ On the other hand, any water on the surface of the aggregate will contribute to the water in the mix and will occupy a volume in excess of that of the aggregate particles.
- ✓ The basic state of the aggregate is ***saturated and surface-dry (S.S.D)*** **(Figure 3).**

Moisture content: is the surface moisture expressed as a percentage of the mass of the saturated and surface-dry aggregate.

Absorption : is the water contained in aggregate in a saturated and surface dry condition.

Total water content of a moist aggregate : is equal to the sum of absorption and moisture content.

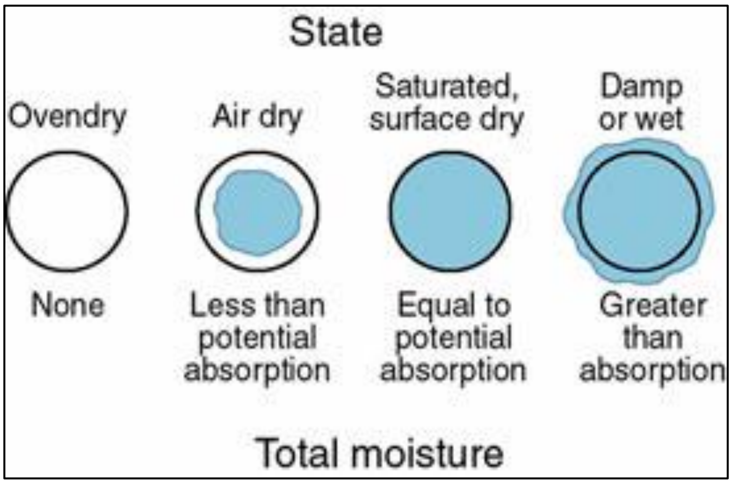

Figure (3): Moisture conditions of aggregate

- **Oven-dry (OD)**: All moisture is removed from the aggregate by heating in an oven at 105ºC to constant weight (overnight heating usually is sufficient). All pores are empty.
- **Air-dry (AD):** All moisture removed from surface, but internal pores partially full.
- **Saturated-surface-dry (SSD)**: All pores filled with water, but no film of water on the surface.
- **Dam or Wet:** All pores completely filled with water with a film on the surface.

Bulking of fine aggregate

The presence of moisture in aggregate necessitates correction of the actual mix proportions: the mass of water added to the mix has to be decreased by the mass of the free moisture in the aggregate, and the mass of the wet aggregate must be increased by a like amount.

In the case of sand, there is a second effect of the presence of moisture: bulking.

Bulking: is the increase in the volume of a given mass of sand caused by the films of water pushing the sand particles apart. Bulking does not affect the proportioning of materials by mass but in the case of volume batching, bulking results in a smaller mass of sand occupying the fixed volume of the measuring box. For this reason, the mix becomes deficient in fine aggregate and appears 'stony', and the concrete may be prone to segregation and honeycombing. Also, the yield of concrete is reduced. The remedy of this is by increasing the apparent volume of fine aggregate (sand) to allow for bulking.

<u>The extent of bulking depends on:</u>

1) The percentage of moisture present in the sand.
2) Fineness of sand.

- The increase in volume relative to that occupied by a *saturated and surface-dry* sand increases with an increase in the moisture content of the sand up to a value of some (5 -8%) when the bulking of (20-30%) occupy.

<u>Upon further addition of water:</u>

The firms merge and the water moves into the voids between the particles so that the total volume of sand decreases until, when fully saturated (flooded), its volume is approximately the same as the volume of dry sand for the same method of filling the container.

***extremely fine sand has been known to bulk as much as 40% at a moisture content of 10%. Such sand is not used for the production of good quality concrete.**

Note: coarse aggregate shows only a negligible increase in volume due to the presence of free water as the thickness of moisture films is very small compared with the particle size.

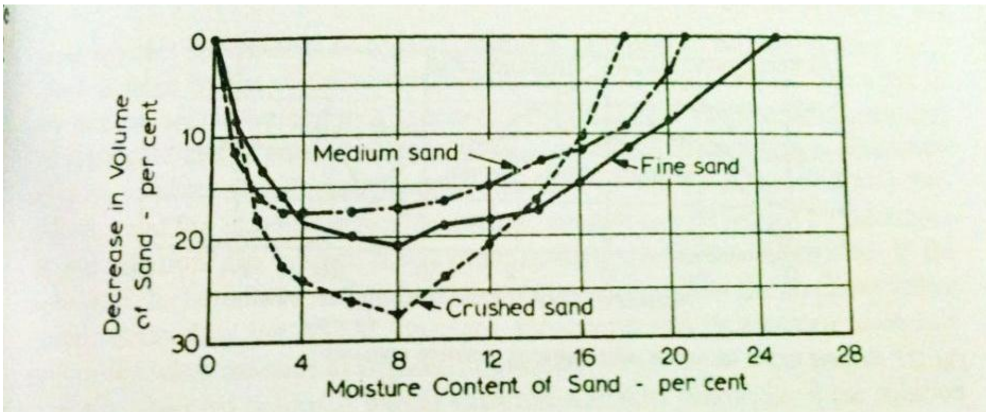

Fig. 3.6 Decrease in true volume of sand due to bulking (for a constant apparent volume of moist sand)

Method to measure the bulking of sand:

Because the volume of saturated sand is the same as that of dry sand, the most convenient way of determining bulking is by measuring the decrease in volume of the given sand when inundated:

A container of known volume is filled with loosely packed moist sand. The sand is then tipped out, the container is partially filled with water and the sand is gradually fed back, with stirring and rodding to expel all air bubbles. The bulking factor is calculated as shown below:

Bulking Factor (B.F) =1+ $\frac{V_m - V_s}{V_s} = \frac{V_m}{V_s}$

where:

V_s: The volume of sand in the saturated sate.

V_m: is the initial apparent volume of the sand (volume of the container).

B.F ≈ (1.2-1.3)

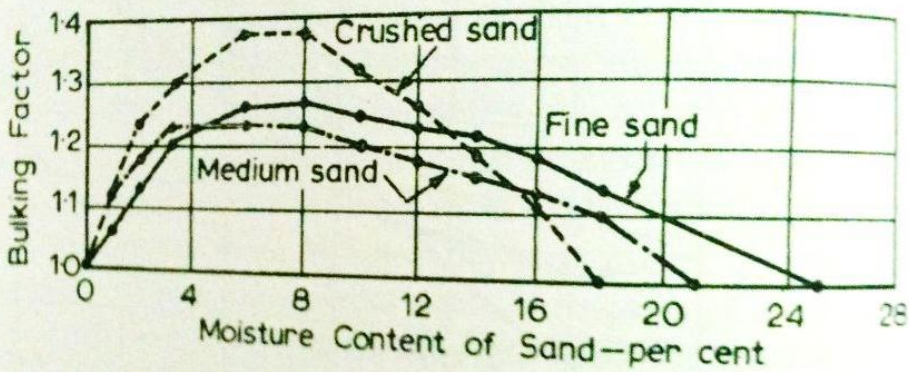

Fig. 3.7 Bulking factor for sands with different moisture contents