UNIT-2

Aggregates form an essential part of many construction projects, from large-scale commercial to smaller domestic works. Whether you need aggregates to form a sub-base for foundations or paving, decorative aggregates for driveways and footpaths – or simply need something to fill in unsightly holes – you should know which kind of aggregates will work best.

In this article, we’ll run through the different classifications of aggregates, based on their varying properties.

Contents:

- Classification of aggregates based on: Grain Size
- Classification of aggregates based on: Density
- Classification of aggregates based on: Geographical Origin
- Classification of aggregates based on: Shape

❖ Classification of aggregates based on: Grain Size

If you separate aggregates by size, there are two overriding categories:

1. Fine
2. Coarse

The size of fine aggregates is defined as 4.75mm or smaller. That is, aggregates which can be passed through a number 4 sieve, with a mesh size of 4.75mm. Fine aggregates include things such as sand, silt and clay. Crushed stone and crushed gravel might also fall under this category.

Typically, fine aggregates are used to improve workability of a concrete mix.

Coarse aggregates measure above the 4.75mm limit. These are more likely to be natural stone or gravel that has not been crushed or processed. These aggregates will reduce the amount of water needed for a concrete mix, which may also reduce workability but improve its innate strength.

❖ Classification of aggregates based on: Density

There are three weight-based variations of aggregates:

1. Lightweight
2. Standard
3. High density

Different density aggregates will have much different applications. Lightweight and ultra lightweight aggregates are more porous than their heavier counterparts, so they can be put to great use in green roof construction, for example. They are also used in mixes for concrete blocks and pavements, as well as insulation and fireproofing.

High density aggregates are used to form heavyweight concrete. They are used for when high strength, durable concrete structures are required – building foundations or pipework ballasting, for example.

❖ **Classifications of aggregates based on: Geographical Origin**

Another way to classify aggregates is by their origin. You can do this with two groups:

- **Natural –** Aggregates taken from natural sources, such as riverbeds, quarries and mines. Sand, gravel, stone and rock are the most common, and these can be fine or coarse.
- **Processed** – Also called 'artificial aggregates', or 'by-product' aggregates, they are commonly taken from industrial or engineering waste, then treated to form construction aggregates for high quality concrete. Common processed aggregates include industrial slag, as well as burnt clay. Processed aggregates are used for both lightweight and high-density concrete mixes.

❖ **Classifications of aggregates based on: Shape**

Shape is one of the most effective ways of differentiating aggregates. The shape of your chosen aggregates will have a significant effect on the workability of your concrete. Aggregates purchased in batches from a reputable supplier can be consistent in shape, if required, but you can also mix aggregate shapes if you need to.

The different shapes of aggregates are:

1) **Rounded–** Natural aggregates smoothed by weathering, erosion and attrition. Rocks, stone, sand and gravel found in riverbeds are your most common rounded aggregates. Rounded aggregates are the main factor behind workability.
2) **Irregular** – These are also shaped by attrition, but are not fully rounded. These consist of small stones and gravel, and offer reduced workability to rounded aggregates.
3) **Angular** – Used for higher strength concrete, angular aggregates come in the form of crushed rock and stone. Workability is low, but this can be offset by filling voids with rounded or smaller aggregates.
4) **Flaky –** Defined as aggregates that are thin in comparison to length and width. Increases surface area in a concrete mix.

5) **Elongated –** Also adds more surface area to a mix – meaning more cement paste is needed. Elongated aggregates are longer than they are thick or wide.

6) **Flaky and elongated –** A mix of the previous two – and the least efficient form of aggregate with regards to workability.

Mechanical Properties of Aggregate

Several mechanical properties of aggregate are of interest for the manufacture of concrete, specially high strength concrete subjected to high wear. Some of them are discussed here in brief:

1. Toughness
2. Hardness
3. Specific Gravity
4. Porosity of Aggregate
5. Bulking of Sand.

1. Toughness:
It is defined as the resistance of aggregate to failure by impact. The impact value of bulk aggregate can be determined as per I.S. 2386, 1963.

The test procedure is as follows:

The aggregate shall be taken as in the case of crushing strength value test i.e., the aggregate should pass through 12.5 mm I.S. sieve and retained on 10 mm I.S. sieve. It should be oven dried at 100°C to 110°C for four hours and then air cooled before test.

Now the prepared aggregate is filled upto 1/3rd height of the cylindrical cup of the equipment. The dia-meter and depth of the cup are 102 mm and 50 mm respectively. After filling the cup upto 1/3rd of its height, the aggregate is tamped with 25 strokes of the rounded end of the tamping rod.

After this operation the cup shall be further filled upto 2/3rd of its height and a further tamping of 25 strokes given. The cup finally shall be filled to over flowing and tamped with 25 strokes and surplus aggre-gate removed and the weight of aggregate noted. The value of weight will be useful to repeat the experi-ment.

Now the hammer of the equipment weighting 14.0 kg or 13.5 kg is raised till its lower face is 380 mm above the upper surface of the aggregate and., allowed to fall freely on the aggregate and the process is repeated for 15 times.

The crushed aggregate is now removed from the cup and sieved through 2.36 mm I.S. sieve. The fraction passing through the sieve is weighed accurately.

Let the weight of oven dry sample in the cup = W kg.

Weight of aggregate passing 2.36 mm sieve = W1 kg.

Then impact value = [(W1/W) x 100]

This value should not be more 30% for aggregate to be used in concrete for wearing surfaces as road and 45% for other type of concrete.

2. Hardness:

It is defined as the resistance to wear by abrasion, and the aggregate abrasion value is defined as the percentage loss in weight on abrasion.

For testing hardness of aggregate following three methods can be used:

(a) Deval Attrition test.

(b) Dorry abrasion test.

(c) Los Angeles test.

(a) Deval Attrition Test:

This test has been covered by IS 2386 Part (IV)-1963. In this test particles of known weight are subjected to wear in an iron cylinder rotated 10,000 (ten thousand) times at the rate of 30 to 33 revolutions per minute. After the specified revolution of the cylinder the material is taken out and sieved on 1.7 mm sieve and the percentage of material finer than 1.7mm is determined. This percentage is taken as the attrition value of the aggregate. The attrition value of about 7 to 8 usually is considered as permissible.

(b) Dorry Abrasion Test:

This test has not been covered by Indian standard specifications. In this test a cylindrical specimen having its diameter and height of 25 cm is subjected to abrasion against a rotating metal disk sprinkled with quartz sand. The loss in weight of the cylinder after 1000 (one thousand) revolu-tions is determined.

Then the hardness of rock sample is expressed by an empirical relation as follows:

Hardness or sample = 20 – Loss in weight in grams/3
For good rock this value should not be less the 17. The rock having this value of 14 is considered poor.

(c) Los-Angeles Test:

This test has been covered by IS 2386 (Part-IV) 1963. In this test aggregate of the specified grading is placed in a cylindrical drum of inside length and diameter of 500 mm and 700 mm respectively. This cylinder is mounted horizontally on stub shafts. For abrasive charge, steel balls or cast iron balls of approximately 48 mm diameter and each weighting 390 grams to 445 gram are used. The numbers of balls used vary from 6 to 12 depending upon the grading of the aggregate. For 10 mm size aggregate 6 balls are used and for aggregates bigger than 20 mm size usually 12 balls are used.

Procedure:

For the conduct of test, the sample and the abrasive charge are placed in the Los-Angeles testing machine and it is rotated at a speed of 20 to 33 revolutions per minute. For aggregates upto 40 mm size the machine is rotated for 500 revolutions and for bigger size aggregate 1000 revolutions. The charge is taken out from the machine and sieved on 1.7 mm sieve.
Let the weight of oven dry sample put in the drum = W Kg.
Weight of aggregate passing through 1.7 sieve = W1 Kg.
Then abrasion value = [(W1/W) x 100]

The abrasion value should not be more than 30% for wearing surfaces and not more than 50% for con-crete used for other than wearing surface. The results of Los Angeles test show good correlation not only the actual wear of aggregate when used in concrete, but also with the compression and flexural strength of concrete made with the given aggregate.

Table 4.8 gives an idea of toughness, hardness, crushing strength etc. of different rocks.

3. Specific Gravity:

The specific gravity of a substance is the ratio of the weight of unit volume of the substance to the unit volume of water at the stated temp. In concrete making, aggregates generally contain pores both permeable and impermeable hence the term specific gravity has to be defined carefully. Actually there are several types of specific gravity. In concrete technology specific gravity is used for the calculation of quantities of ingre-dients. Usually the specific gravity of most aggregates varies between 2.6 and 2.8.

Specific gravity of certain materials as per concrete hand book CA-1 Bombay may be assumed as shown in Table 4.9.

Table 4.9. Specific gravity of cement and aggregate

Material	*Specific gravity*
Cement	3.15
Average sand	2.00
Granite	2.80
Gravel	2.66
Sand	2.65

Method of Determination of Specific Gravity of Aggregate:

IS-2386-Part-III-1963 describes various procedures to find out the specific gravity of aggregates of different sizes. Here the method applicable to aggregates larger than 10 mm in size has been described as follows:

A sample of aggregate not less than 2 kg in weight is taken and washed thoroughly to remove dust, and silt particles etc. The washed sample is placed in a wire basket and immersed in distilled water at a tem-perature of 27 ± 5°C.

Immediately after immersion, the entrapped air is removed from the sample by lifting the basket con-taining sample 25 mm above the bottom of the jar or tank and allow it drop 25 times at the rate of 1 mm per sec. During this operation, care should be taken that basket and aggregate remain fully immersed in water. After this, the sample is kept in water for about 24 ± ½ hour.

After this period the basket and aggregate is given a jerk to remove the air etc. and weighed in water at the temperature of 27 ± 5°C. Let the weight of basket and aggregate be A1. The basket and sample of aggregate is removed from the water and allowed to drain for a few minutes. Then the aggregate is taken out from the basket and placed on a dry cloth and dried further. The empty basket is again immersed in water and weighed in water after giving 25 jolts. Let this weight be A2.

The aggregate is surface dried in shade for not more than 10 minutes and the aggregate is weighed in air. Let this weight be B. Now the agg-regate is oven dried for 24 ± ½ hour at a temperature of 100 to 110°C. It is then cooled in air tight container and weighed. Let this weight be C.

Thus,

Weight of sample in water = (A1 – A2) = A
Weight of saturated surface dry in air sample = B
Weight of oven dry sample = C
(a) Then specific gravity = [C/(B – A)]
(b) Apparent specific gravity = [C/(C – A)]
(c) Water absorption = 100 (B – C)
(d) Bulk density = Net weight of the aggregate in kg./capacity or the container in litres
Example:

Find the value of- (i) Specific gravity, (ii) Apparent specific gravity, (iii) Apparent particle density, (iv) Bulk particle density.

(i) Mass of oven dry sample C = 480 gram
(ii) Mass of saturated surface dried sample in air B = 490 gram
(iii) Weight of vessel with water = 1400 gram
(iv) Weight of vessel + water + sample = 1695 gram.
Solution:
(i) Specific gravity = [mass of oven dry sample/(mass or saturated surface sample – sample weight in water)]
= [C/(B – A)] = [480/(490-295)]
= 480/195 = 2.50
(ii) Apparent specific gravity = [C/(C – A)] = [480/(480 – 295)]
= 480/185 = 2.59
(iii) Apparent particle density = 1000 x Apparent specific gravity = 2.59 x 1000
= 2590 kg/m3
(iv) Bulk Particle density = Bulk specific gravity x 1000
= 2.59 x 1000 = 2500 kg/m3

Absolute Specific Gravity:

It can be defined as the ratio of the weight of the solid, referred to vacuum, to the weight of an equal volume of gas free distilled water both taken at the standard or a stated temperature, usually it is not required in concrete technology. Actually the absolute specific gravity and particle density refer to the volume of solid material excluding all pores, while apparent specific gravity and apparent particle density refer to the value of solid material including impermeable pores, but not the capi-llary pores. In concrete technology apparent specific gravity is required.

Apparent Specific Gravity:

It can be defined as the ratio of the weight of the aggregate dried in an oven at 100°C to 110°C for 24 hours to the weight of water occupying a volume equal to that of the solid including the impermeable pores. This can be determined by using pycno-meter for solids less than 10 mm in size i.e., sand.

Bulk Specific Gravity:

It can be defined as the ratio of the weight in air of a given volume of material (including both permeable and impermeable voids) at the standard temperature to the weight in air of an equal volume of distilled water at the same standard temperature (20°C). The specific gravity of a material multiplied by the unit weight of water gives the weight of 1 cubic metre of that substance. Some times this weight is known as solid unit weight. The weight of a given quantity of particles divided by the solid unit weight gives the solid volume of the particles.

Solid vol. in m3 = 3 wt. of substance in kg/specific gravity x 1000

Bulk Density:

The weight of aggregate that would fill a container of unit volume is known as bulk density of aggregate. Its value for different materials as per concrete hand book CIA Bombay is shown in Table 4.10.

Table 4.10. Bulk density kg/lit. (concrete hand book CA-1 Bombay)

Material	*Specific gravity*
Cement	1.44
River sand fine	1.44
Medium	1.52
Coarse	1.60
River shingle	1.60
Broken stone	1.60
Stone screaning	1.44
Broken Granite	1.68

Voids:

With respect to a mass of aggregate, the term voids refers to the space between the aggregate particles. Numerically this voids space is the difference between the gross volume of aggregate mass and the space occupied by the particles alone. The knowledge of voids of coarse and fine aggregate is useful in the mix design of concrete.

Percentage voids = $[(Gs - g)/Gs] \times 100$

where Gs = specific gravity of aggregate and g is bulk density in kg/litre.

Unit Weight:

The weight of a unit volume of aggregate is called as unit weight. For a given specific gravity, greater the unit weight, the smaller the percentage of voids and better the gradation of the particles, which affects the strength of concrete to a great extent.

4. Porosity and Absorption of Water by Aggregate:

All aggregates, particles have pores with in their body. The characteri-stics of these pores are very important in the study of the properties of aggregate. The porosity, permeability, and absorption of aggregates in-fluence the resistance of concrete to freezing and thawing, bond strength between aggregate and cement paste, resistance to abrasion of concrete etc.

The size of pores in the aggregate varies over a wide range, some being very large, which could be seen even with naked eye. The smallest pore of aggregate is generally larger than the gel pores in the cement paste, pores smaller than 4 microns are of special interest as they are believed to affect the durability of aggregates subjected to alternate freezing and thawing. Some of the pores are wholly within the body of the aggregate particles and some of them are open upto the surface of the particle.

The cement paste due to its viscosity cannot penetrate to a great depth into the pores except the largest of the aggregate pores. Therefore, for the purpose of calculating the aggregate content in concrete, the gross volume of the aggregate particles is considered solid. However water can enter these pores, the amount and rate of penetration depends upon the size, continuity and total volume of pores.

When all the pores in the aggregate are full with water, then the aggregate is said to be saturated and surface dry. If this aggregate is allowed to stand in the laboratory, some of the moisture will evaporate and the aggregate will be known as air dry aggregate. If aggregate is dried in oven and no moisture is left in it, then it is known as bone dry aggregate. Thus the ratio of the increase in weight to the dry weight of the sample, expressed as a percentage is known as absorption.

The knowledge of absorption of aggregate is important in adjusting water-cement ratio of the concrete. If water available in the aggregate is such that it contributes some water to the dilution of cement paste, in that case the water-cement ratio will be more than the required and the strength will go down.

On the other hand, if the aggregate is so dry that it will absorb some of the mixing water, in that case the mix will have lower water-cement ratio and the mix may become unworkable. Hence, while deciding the water-cement ratio, it is assumed that the aggregate is in saturated but surface dry condition, i.e. neither it will add water to cement paste, nor it will absorb water from the mix.

It has been observed that absorption of water by dry aggregate slows down due to the coating of particles with cement paste. The water absorption by aggregate should be determined for 10 to 30 minutes instead of total water absorption. The value of absorption of water may be taken as follows as recommended by concrete hand book CAI Bombay in Table 4.11.

Table 4.11. Water absorption by aggregates

S. No.	*Aggregate*	*Moisture absorbed by wt of aggregate*
1.	Average sand	1.0 %
2.	Pebbles and crushed lime stone	1.0 %
3.	Granite and trap rock	0.5 %
4.	Porous sand stone	7.0 %
5.	Very light and porous aggregate	25.0 %

4.Surface Water:

While using aggregate in the concrete, water on the surface of the aggregate should be taken into account, as it will contribute to the water in the mix and will affect the water-cement ratio of the mix, causing lower strength of the concrete. It is difficult to measure surface water of the aggregate. Therefore its value may be assumed according to I.S. 456, 1964 given in Table 4.12.

Table 4.12. Surface water carried by average aggregate

S. No.	*Aggregate*	*App. quantity of surface water in lit/m³*
1.	Very wet sand	120.0
2.	Moderately wet sand	80.0
3.	Moist sand	40.0
4.	Moist gravel or crushed rock (as coarser the aggregate, lesser the surface water)	20 to 40

5. Bulking of Sand:

The moisture present in fine aggregate causes increase in its volume, known as bulking of sand. The moisture in the fine aggregate develops a film of moisture around the particles of sand and due to surface tension pushes apart the sand particles, occupying greater volume. The bulking of the sand affects the mix proportion, if mix is designed by volume batching. Bulking results in smaller weight of sand occupying the fixed volume of the measuring box, and the mix becomes deficient in sand and the resulting concrete becomes honeycombed and its yield is also reduced.

The extent of bulking depends upon the percentage of moisture present in sand and its fineness. The increase in volume relative to that occupied by a satura-ted and surface dry sand increases with an increase in the moisture content of the sand upto a value of 5 to 8%, causing bulking ranging from 20 to 40% as shown in Table 4.13. Fig. 4.8 and Table 4.13 shows bulking of sand with various moisture contents as suggested by con-crete hand book CAI, Bombay.

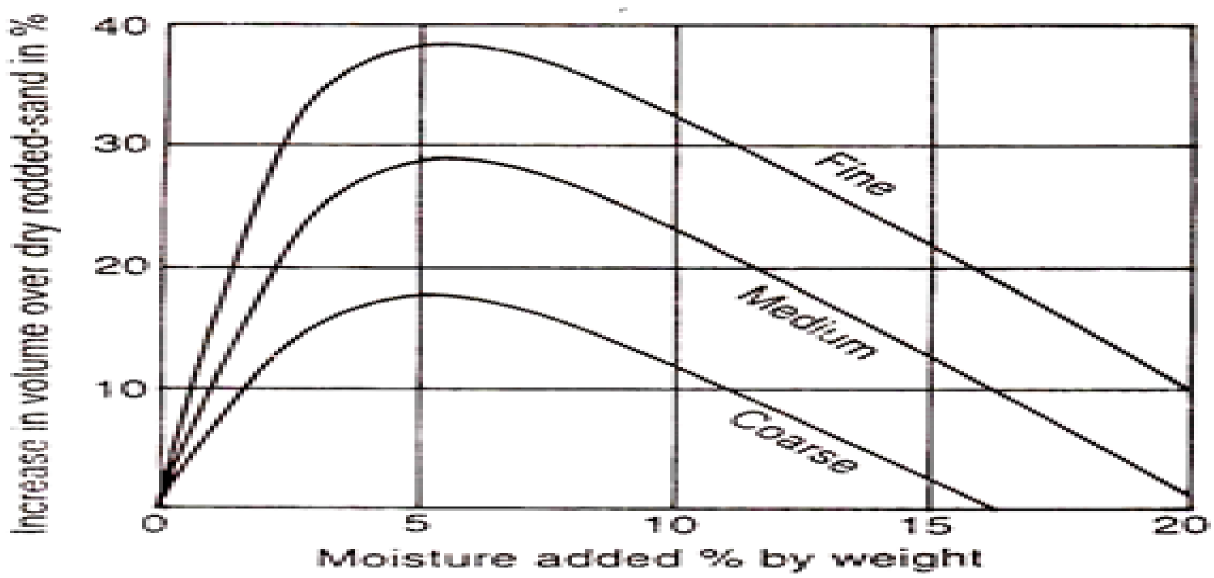


Fig. 4.8. Bulking of sand

Table 4.13.

S. No.	*Moisture percent*	*Percentage bulking*			*Remark*
		Fine sand	*Medium sand*	*Coarse sand*	
1.	1	16	8	6	Coarser the sand, lesser the bulking
2.	2	26	16	12	
3.	3	32	22	15	
4.	4	36	27	17	
5.	5	38.5	29	18	
6.	6	37	28	18	
7.	8	35	26	16	
8.	10	32	22	12	
9.	12	28	19		
10.	15	22	12	8	
11.	17	10	7	0	
12.	20	0	0	0	
13.	27	0	0	0	

As the moisture content increases, the film of water formed around the sand particles merge and the water moves into the voids between the particles so that the total volume of sand decreases, till the sand is fully satu-rated. The volume of fully saturated sand is same as that of the dry sand for the same method of filling the con-tainer.

Determination of Bulking of Sand:

Since the volume of saturated sand is same as that of dry sand, the most convenient way of determining bulking of sand is by measuring the decrease in volume of the given sand on saturation. For the measurement of bulking of sand, usually a container of known volume, a 30 cm long steel rule, and a 6 mm iron rod is required.

Procedure:

Put sufficient quantity of sand loosely into the container, till it is about two-thirds full. Level off the top of the sand with steel rule, and push this rule at the middle of the surface to the bottom of the container and measure its height. Let the height be h cm.

Now empty this sand into another container. While emptying, care should be taken that no sand parti-cles are lost. Take about 1/3rd to half-full the first container with water and add about half the sand to it and rod it with 6 mm diameter steel rod. The sand should be rodded till the air bubbles cease to come out. At this stage the volume of sand is minimum. At this stage add the remaining sand and rod it also till air bubbles cease to come out. Smooth and level the top surface of the saturated sand and measure its height by pushing the steel rule at the middle of the surface to the bottom of the container. Let this height be h1 cm.

Then % bulking = [(h1/h1) x 100]

Effect of Bulking of Sand:

For volume batching, bulking has to be allowed for by increasing the total volume of sand used, otherwise the mix will be deficient in sand and segregation of the mix may take place. Also the resulting concrete will be honeycombed and its yield will be reduced, raising its cost of production. The volume to be increased can be calculated either by knowing this percentage of bulking as shown above or by bulking factor.

If,

Vm = vol. of moist sand

Vs = vol. of saturated sand

then bulking = [(Vm – Vs)/Vs]

and bulking factor = 1 + [(Vm – Vs)/Vs] = Vm/Vs

Hence to know the total volume of sand to be used can be calculated by multiplying the vol. Vs by the bulking factor. The value of bulking factor can be determined by the curves of Fig. 4.9. Fig. 4.9 gives bul-king factor against moisture content upto 20% for three types of sands.

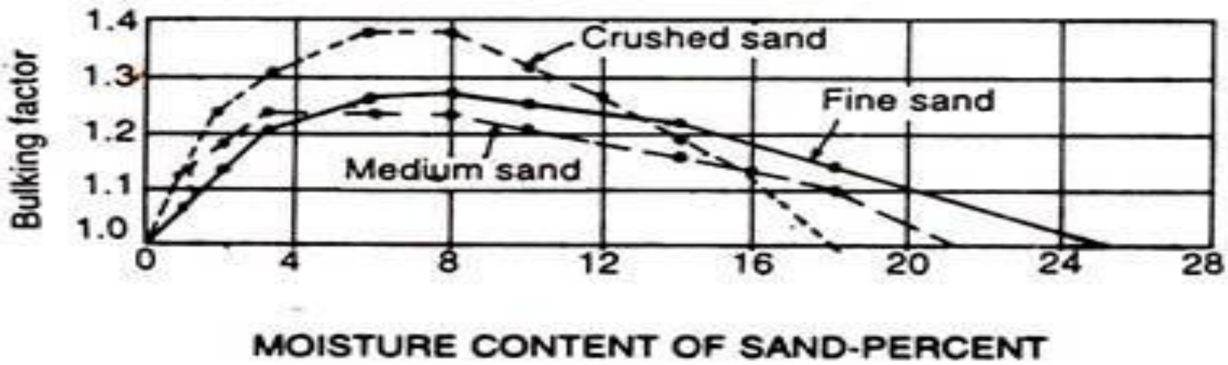
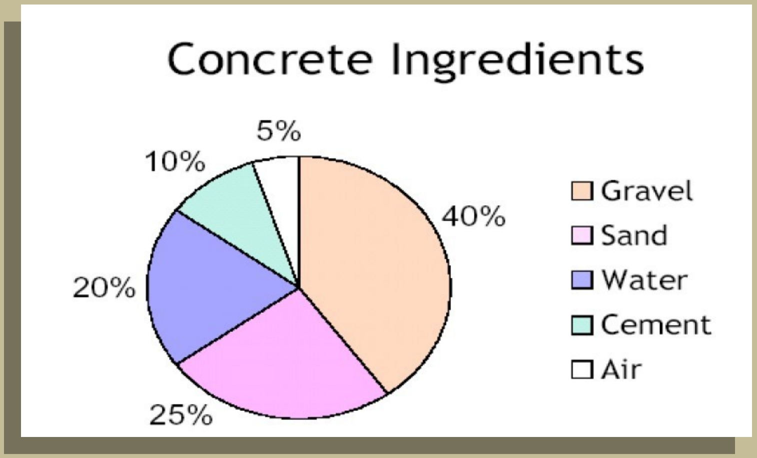


Fig. 4.9. Bulking factor for sand with different moisture contents

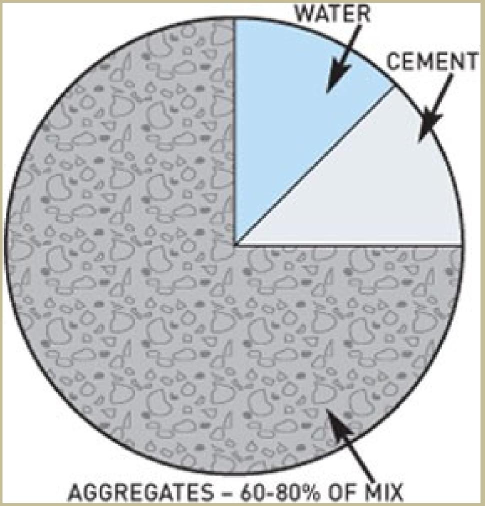
Aggregates

- **Aggregates generally occupy 65- 80% of a concrete's volume.** Aggregates are inert fillers floating in the cement paste matrix for concretes of low strength. The strength of aggregates do not contribute to the strength of concrete for low strength concrete**. The characteristics of aggregates impact performance of fresh and hardened concrete.**



Why use aggregate

- **Reduce the cost of the concrete** – 1/4 - 1/8 of the cement price
- **Reduce thermal cracking** – 100 kg of OPC produces about 12^{o} C temperature rise
- **Reduces shrinkage** – 10% reduction in aggregate volume can double shrinkage
- **High aggregate** : cement ratio (A/C) desirable
- **A/C mainly influenced by cement content**
- **Imparts unit weight to** concrete



Aggregate Classification

- **Size:-** Coarse Aggregates & Fine Aggregates.
- **Specific Gravity:-** Light Weight, Normal Weight and Heavy Weight Aggregates.
- **Availability:-** Natural Gravel and Crushed Aggregates.
- **Shape:-** Round, Cubical, Angular, Elongated and Flaky Aggregates.
- **Texture:-** Smooth, Granular, Crystalline, honeycombed and Porous.

Aggregate Classification : Size

- **Fine Aggregate**
- Sand and/or crushed stone.
- < 4.75 mm.
- F.A. content usually 35% to 45% by mass or volume of total aggregate.

- **Coarse Aggregate**
- Gravel and crushed stone.
- >4.75 mm.
- Typically between 9.5 and 37.5 mm.

Aggregate Classification : Specific Gravity

- **Normal-Weight Aggregate**

Most common aggregates (Ex: Sand, Gravel, Crushed stone)

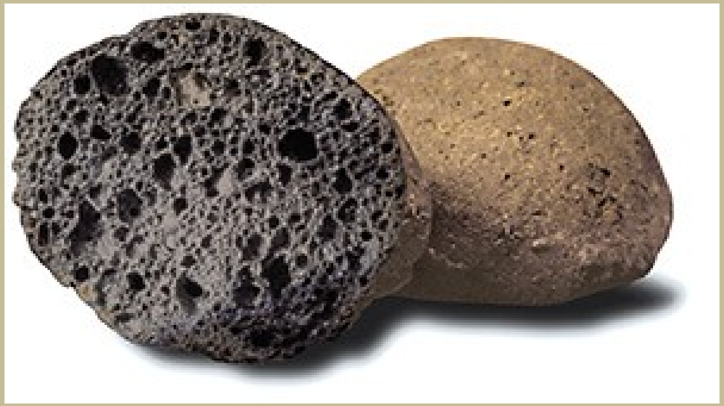
- Produce normal-weight concrete 2200 to 2400 kg/m^3

- **Lightweight Aggregate**
- Expanded (Shale, Clay, Slate, Slag)
- Produce structural lightweight concrete 1350 to 1850 kg/m^3
- And (Pumice, Scoria, Perlite, Diatomite)

Produce lightweight insulating concrete— 250 to 1450 kg/m^3

Normal Weight Aggregates
(Ex: Sand, Gravel, Crushed stone)

Lightweight Aggregate
(Shale, Clay, Slate, Slag)



Aggregate Classification : Specific Gravity

- **Heavyweight Aggregate**
- Barite, Limonite, Magnetite, Hematite, Iron
- Produce high-density concrete up to 6400 kg/m^3
- Used for Radiation Shielding

Aggregate Classification : Availability

- **Natural Gravel**
- River or seashore gravels; desert, seashore and windblown sands
- Rounded in nature

  Fully water worn or completely shaped by attrition

- **Crushed Aggregates.**
- Crushed rocks of all types; talus; screes

  Angular in nature

Aggregate Classification : Shape

- The shape of aggregates is an important characteristic since it affects the workability of concrete.

Round (spherical) concrete aggregate.

Flaky concrete aggregate.

Crushed concrete aggregate.

Aggregate Classification : Shape

Aggregate Classification : Shape

Classification	*Description*	*Examples*
Rounded	Fully water worn or completely shaped by attrition	River or seashore gravels; desert, seashore and wind-blown sands
Irregular or Partly rounded	Naturally irregular or partly shaped by attrition, having rounded edges	Pit sands and gravels; land or dug flints; cuboid rock
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types; talus; screes
Flaky	Material, usually angular, of which the thickness is small relative to the width and/or length	Laminated rocks

Aggregate Classification : Texture

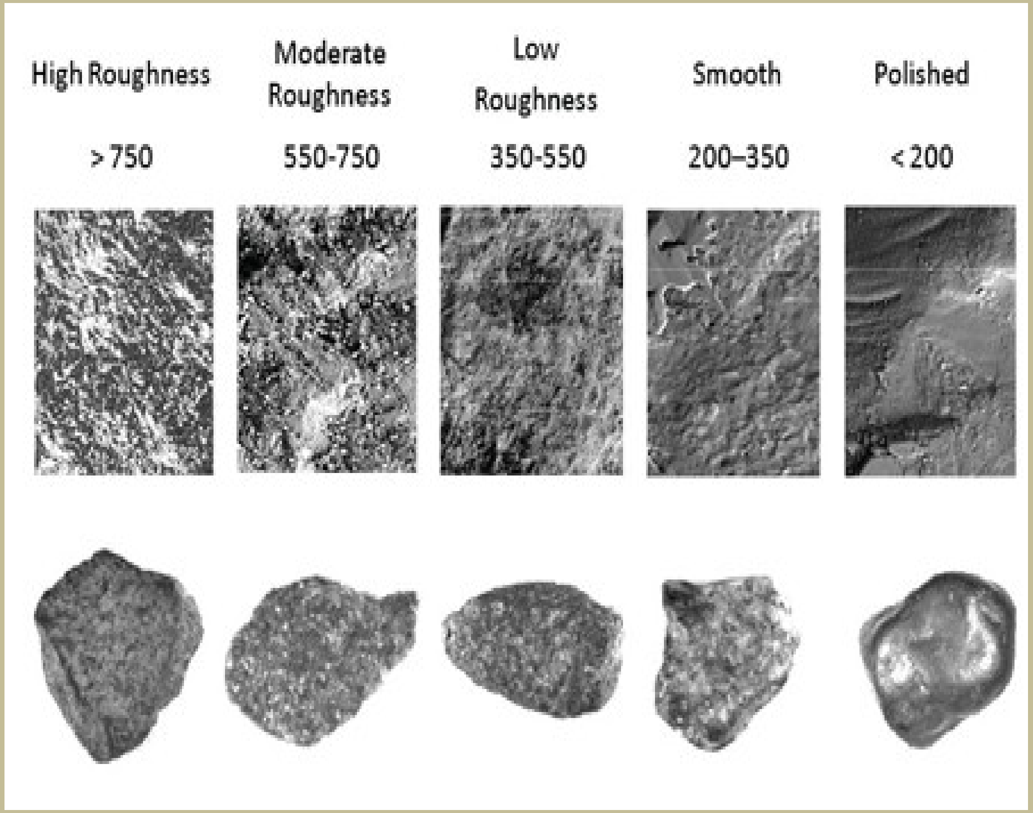
- **Surface texture is the property, the measure of which depends upon the relative degree to which particle surfaces are polished** or dull, smooth or rough.
- Surface texture depends on **hardness, grain size, pore structure, structure of the rock.**

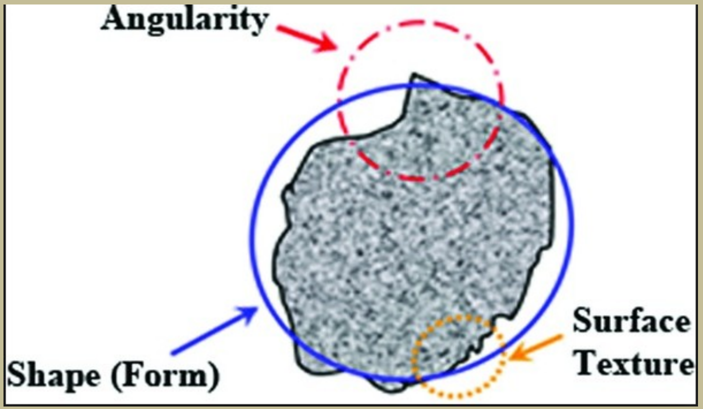
Per cent of Particles		*Water/Cement Ratio*	*Strength 28 days MPa*	
Smooth	*Rough*		*Flexural*	*Compressive*
100	0	0.54	4.3	34.8
50	50	0.57	4.6	32.1
0	100	0.60	4.8	29.5

Aggregate Classification : Texture

Group	Surface Texture	Examples
1.	Glassy	Black flint
2.	Smooth	Chert; slate; marble; some rhyolite
3.	Granular	Sandstone; oolites
4.	Crystalline	Fine : Basalt; trachyte; medium : Dolerite; granophyre; granulite; microgranite; some limestones; many dolomites. Coarse : Gabbro; gneiss; granite; granodiorite; syenite
5.	Honeycombed and porous	Scoria; Pumice, trass.

Aggregate Classification : Texture





Physical Prosperities of Aggregate : Grading

Grading is the particle-size distribution of an aggregate as determined by a sieve analysis using wire mesh sieves with square openings.

As per IS:2386(Part-1)

Fine aggregate : 6 standard sieves with openings from 150 µm to 4.75 mm. (150 µm, 300 µm, 600 µm, 1.18mm, 2.36mm, 4.75mm)

Coarse aggregate: 5 sieves with openings from 4.75mm to 80 mm. (4.75mm, 10mm, 12.5mm, 20mm, 40mm)

Physical Prosperities of Aggregate : Grading

Physical Prosperities of Aggregate : Grading

- **Grain size distribution for concrete mixes that will provide a dense strong mixture.**
- **Ensure that the voids between the larger particles are filled with medium particles**. The remaining voids are filled with still smaller particles until the smallest voids are filled with a small amount of fines.

Grading of Fine Aggregate

I.S. Sieve Designation	Percentage passing by weight for Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90–100	90–100	90–100	95–100
2.36 mm	60–95	75–100	85–100	95–100
1.18 mm	30–70	55–90	75–100	90–100
600 micron	15–34	35–59	60–79	80–100
300 micron	5–20	8–30	12–40	15–50
150 micron	0–10	0–10	0–10	0–15

Grading of Coarse Aggregate

IS Sieve Designation	Percentage passing for single-sized aggregate nominal size (by weight)						Percentage passing for Graded aggregate of nominal size (by weight)			
	63 mm	40 mm	20 mm	16 mm	12.5 mm	10 mm	40 mm	20 mm	16 mm	12.5 mm
80 mm	100	–	–	–	–	–	100	–	–	–
63 mm	85–100	100	–	–	–	–	–	–	–	–
40 mm	0–30	85–100	100	–	–	–	95–100	100	–	–
20 mm	0–5	0–20	85–100	100	–	–	30–70	95–100	100	100
16 mm	–	–	–	85–100	100	–	–	–	90–100	–
12.5 mm	–	–	–	–	85–100	100	–	–	–	90–100
10 mm	–	0–5	0–20	0–30	0–45	85–100	10–35	25–55	30–70	40–85
4.75 mm	–	–	0–5	0–5	0–10	0–20	0–5	0–10	0–10	0–10
2.36 mm	–	–	–	–	–	0–5	–	–	–	–

Grading of All in Aggregate

I.S. Sieve Designation	Percentage by weights passing for all in-aggragrate of	
	40 mm Nominal size	20 mm Nominal size
80 mm	100	–
40 mm	95–100	100
20 mm	45–75	95–100
4.75 mm	25–45	30–50
600 micron	8–30	10–35
150 micron	0–6	0–6

Fineness Modulus (FM)

- **The results of aggregate sieve analysis is expressed by a number called Fineness Modulus.**
- Obtained by adding the sum of the cumulative percentages by mass of a sample aggregate retained on each of a specified series of sieves and dividing the sum by 100.
- The following limits may be taken as guidance:
- Fine sand : Fineness Modulus : 2.2 - 2.6
- Medium sand : F.M. : 2.6 - 2.9
- Coarse sand : F.M. : 2.9 - 3.2

$$\text{Finess Modulus, } FM = \left(\frac{\text{Total of Cumulative Percentage of Passing (\%)}}{100} \right)$$

A sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

Fineness Modulus (FM)

.

$$F.M. = \frac{\sum(\text{cumulative percentage retained on specified sieves})}{100}$$

where:	F.M.	=	fineness modulus
	specified sieves	=	0.150 mm (No. 100), 0.30 mm (No. 50), 0.60 mm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8), 4.75 mm (No. 4), 9.5 mm (0.375-in.), 19.0 mm (0.75-in.), 37.5 mm (1.5-in.), and larger increasing in the size ratio of 2:1.

Physical Properties of Aggregate: Flakiness Index

- **The flakiness index of aggregate is the percentage by weight of particles in it whose least dimension (thickness)** is less than three-fifths of their mean dimension.
- **The test is not applicable to sizes smaller than 6.3 mm.**
- **The flakiness index is taken as the total weight of the material passing the various thickness gauges expressed as a percentage of the total weight of the sample taken**.
- Table 3.18 shows the standard dimensions of thickness and length gauges.

Physical Properties of Aggregate: Flakiness Index

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Physical Properties of Aggregate: Flakiness Index

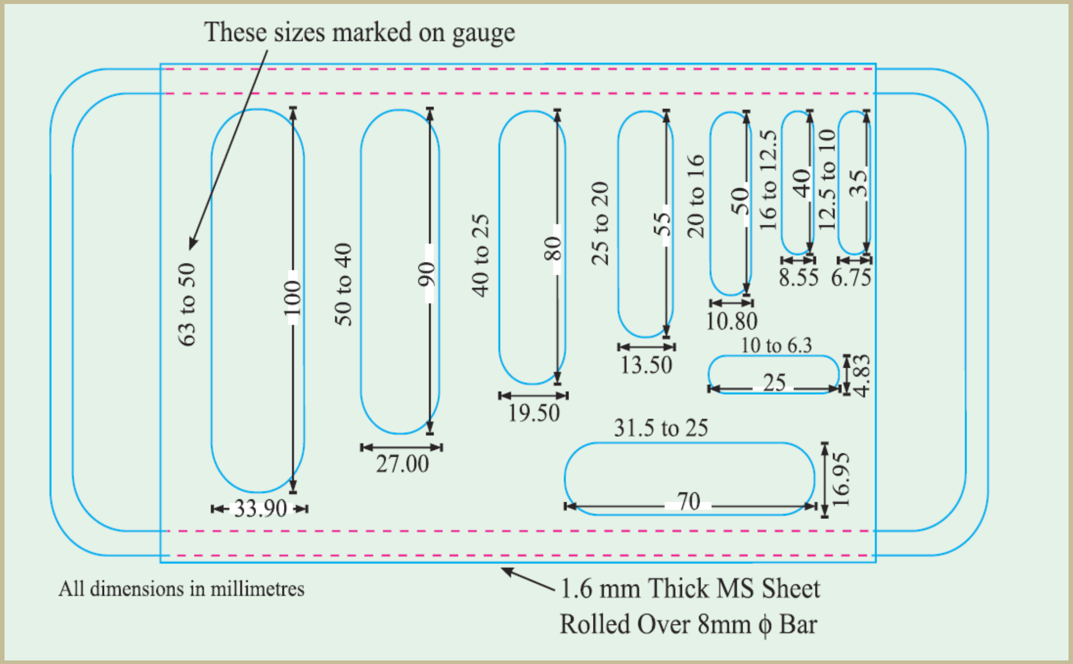
Table 3.18. Shows Dimensions of Thickness and Length Gauges (IS: 2386 (Part I) – 1963)

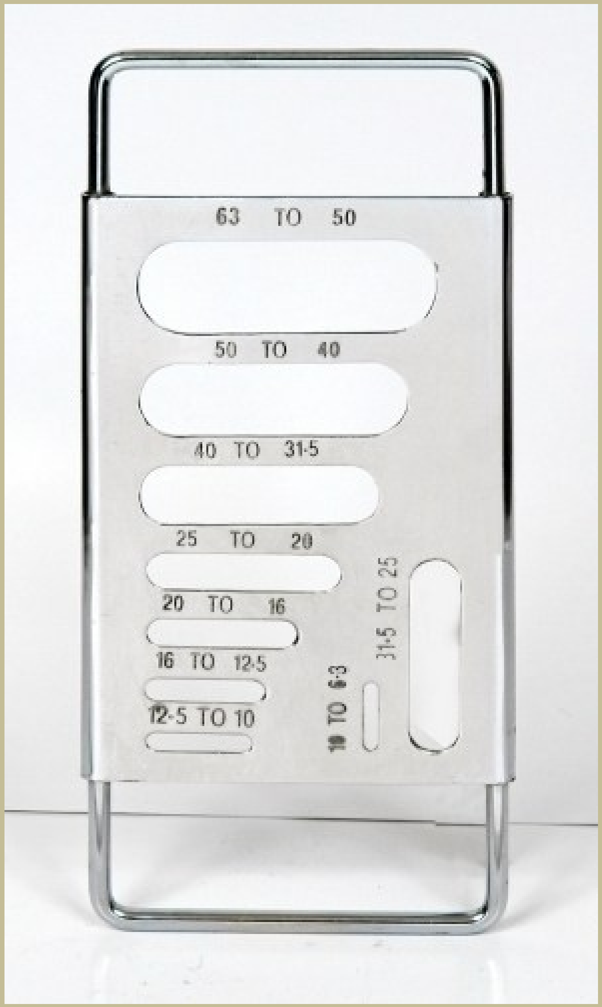
Size of Aggregate Thickness		Length of Gauge* mm	Gauge† mm
Passing through IS Sieve	Retained on IS Sieve		
63 mm	50 mm	33.90	–
50 mm	40 mm	27.00	81.0
40 mm	25 mm	19.50	58.5
31.5 mm	25 mm	16.95	–
25 mm	20 mm	13.50	40.5
20 mm	16 mm	10.80	32.4
16 mm	12.5 mm	8.55	25.6
12.5 mm	10.0 mm	6.75	20.2
10.0 mm	6.3 mm	4.89	14.7

* This dimension is equal to 0.6 times the mean Sieve size.

† This dimension is equal to 1.8 times the mean Sieve size.

Physical Properties of Aggregate: Flakiness Index

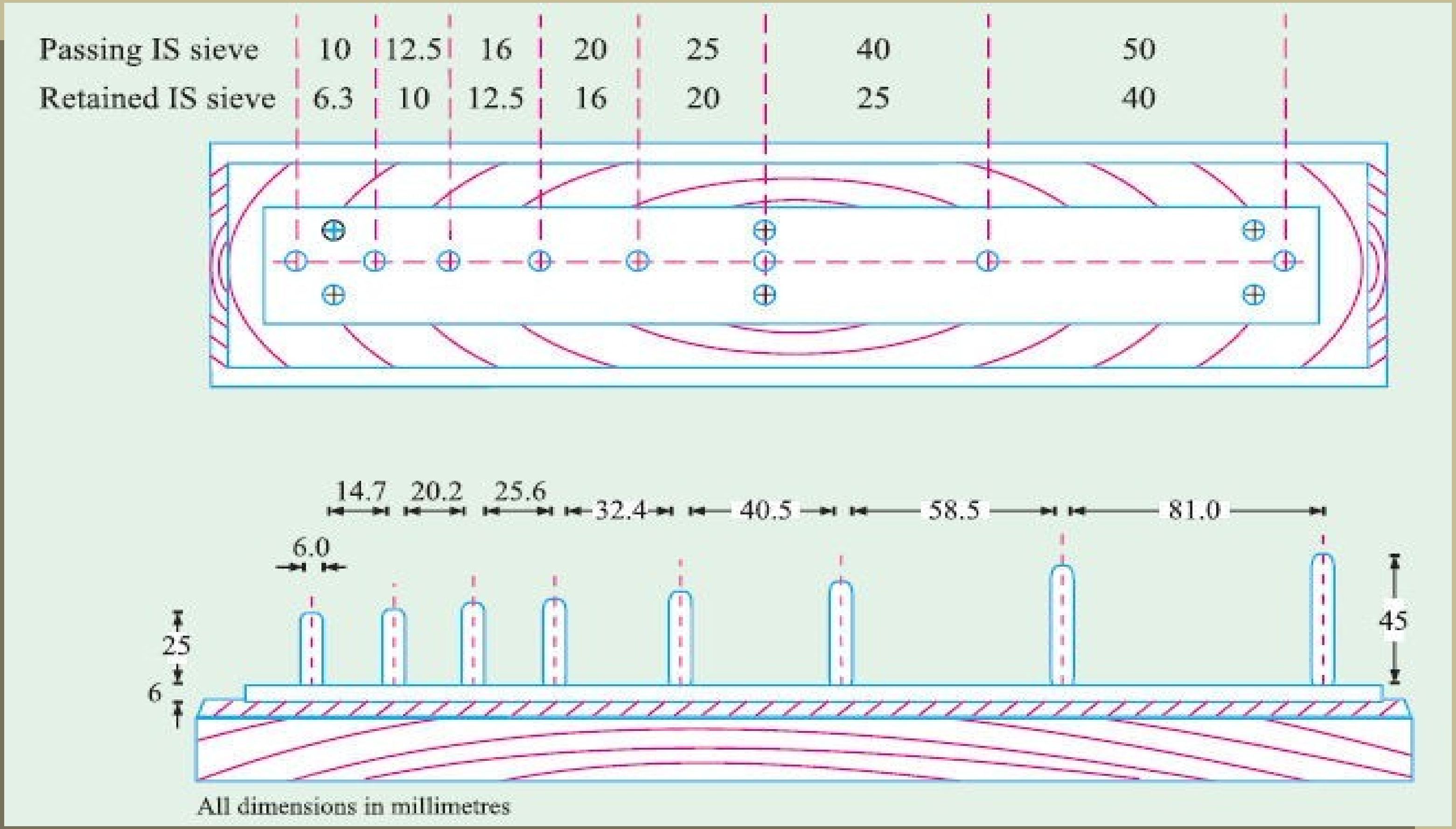




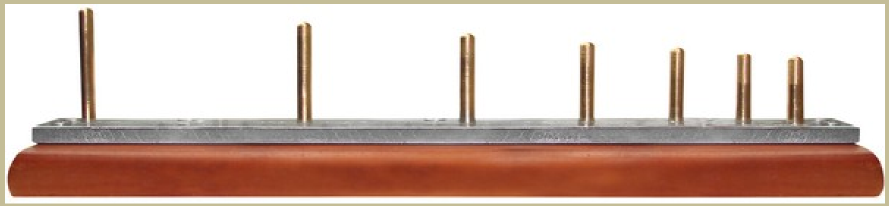
Physical Properties of Aggregate: Elongation Index

- **The elongation index on an aggregate is the percentage by weight of particles whose greatest dimension (length)** is greater than 1.8 times their mean dimension.
- The elongation index is not applicable to sizes smaller than 6.3 mm.
- **The elongation index is the total weight of the material retained on the various length gauges expressed as a percentage of the total weight of the sample gauged. The** presence of elongated particles in excess of 10 to 15 per cent is generally considered undesirable, but no recognized limits are laid down.

Physical Properties of Aggregate: Elongation Index



Physical Properties of Aggregate: Elongation Index



Physical Properties of Aggregate: Specific Gravity

Indian Standard Specification IS : 2386 (Part III) of 1963 gives various procedures to find out the specific gravity of different sizes of aggregates.

$$\text{Specifc Gravity} = \frac{C}{A - B}$$

$$\text{Apparent Specifc Gravity} = \frac{C}{C - B}$$

$$\text{Water Absorption} = \frac{100(B - C)}{C}$$

A = Weight of saturated aggregate in water = $(A_1 - A_2)$ B = Weight of the saturated surface - dry aggregate in air C = Weight of oven-dried aggregate in air.

A_1 = Weight of aggregate and basket in water A_2 = Weight of empty basket in water

Physical Properties of Aggregate: Specific Gravity

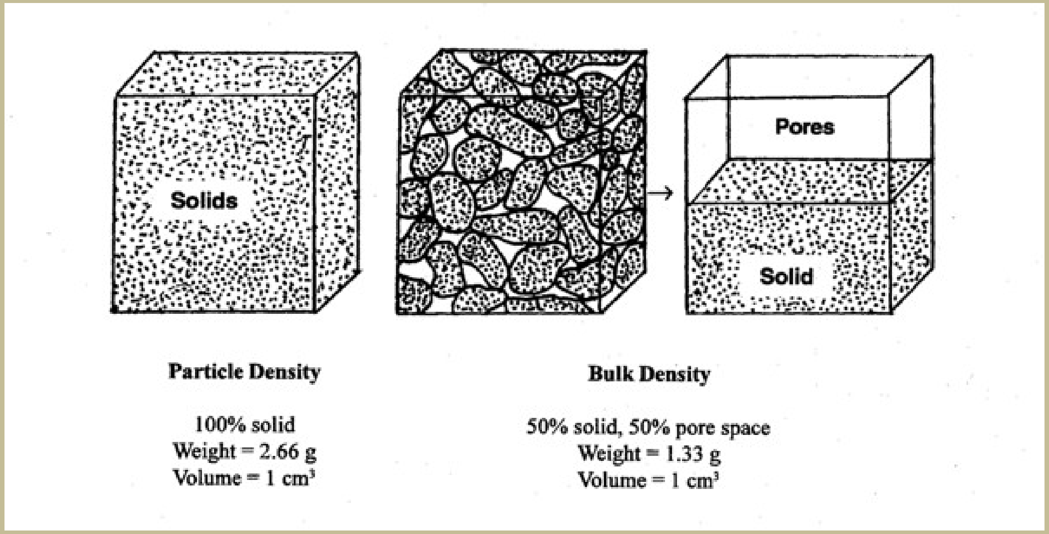
Physical Properties of Aggregate: Bulk Density

- **The cylindrical measure is filled about 1/3 each time with thoroughly mixed aggregate and tamped with 25 strokes by a bullet ended tamping rod, 16 mm diameter and 60 cm long.**
- The net weight of the aggregate in the measure is determined and the bulk density is calculated in kg/litre.

$$\text{Bulk dinsity} = \frac{\text{net weight of the aggregate in kg}}{\text{capacity of the container in litre}}; \qquad \text{Percentage of voids} = \frac{G_s - \gamma}{G_s} \times 100$$

where, G_s = specific gravity of aggregate and γ = bulk dinsity in kg/litre.

Physical Properties of Aggregate: Bulk Density



Mechanical Prosperities of Aggregate : Aggregate Crushing Value

- **The "aggregate crushing value" gives a relative measure of the resistance of an aggregate** to crushing under a gradually applied compressive load.
- **The apparatus, with the test sample and plunger in position**, is placed on the compression testing machine and is loaded uniformly upto a total load of 400 kN in 10 minutes time.
- **The load is then released and the whole of the material removed from the cylinder and sieved on a 2.36 mm I.S. Sieve.**

Mechanical Prosperities of Aggregate : Aggregate Crushing Value

Mechanical Prosperities of Aggregate : Aggregate Crushing Value

- $The\ aggregate\ crushing\ value = \frac{B}{A} \times 100$

  B = weight of fraction passing 2.36 mm sieve,

  A = weight of surface-dry sample taken in mould.

- The aggregate crushing value should not be more than 45 per cent for aggregate used for concrete other than for wearing surfaces, and 30 per cent for concrete used for wearing surfaces such a runways, roads and air field pavements.

Mechanical Prosperities of Aggregate : Aggregate Crushing Value

Mechanical Prosperities of Aggregate : Aggregate Impact Value

- **The aggregate impact value gives relative measure of the resistance of an aggregate to sudden shock or impact**.
- **The whole sample is filled into a cylindrical steel cup firmly fixed on the base of the machine. A hammer weighing about 14 kgs.** is raised to a height of 380 mm above the upper surface of the aggregate in the cup and allowed to fall freely on the aggregate.
- **The test sample shall be subjected to a total 15 such blows each being delivered at an interval of not less than one second.**

Mechanical Prosperities of Aggregate : Aggregate Impact Value

Mechanical Prosperities of Aggregate : Aggregate Impact Value

Mechanical Prosperities of Aggregate : Aggregate Impact Value

- The crushed aggregate is removed from the cup and the whole of it is sieved on 2.36 mm I.S. Sieve.
- $The\ Aggregate\ Impact\ Value = \frac{B}{A} \times 100$

  B = weight of fraction passing 2.36 mm I.S. Sieve.

  A = weight of oven-dried sample.

- The aggregate impact value should not be more than 45 per cent by weight for aggregates used for concrete other than wearing surfaces and 30 per cent by weight for concrete to be used as wearing surfaces, such as runways, roads and pavements.

Mechanical Prosperities of Aggregate : Aggregate Abrasion Value

- **Indian Standard 2386 (Part IV) of 1963 covers two methods for finding out the abrasion value of coarse aggregates:** namely, by the use of Deval abrasion testing machine and by the use of Los Angeles abrasion testing machine.

- **Test sample and abrasive charge are placed in the Los Angeles Abrasion testing machine and the machine is rotated at a speed of 20 to 33 rev/min.**

- **For gradings A, B, C and D, the machine is rotated for 500 revolutions. For gradings E, F and G, it is rotated 1000 revolutions**.

Aggregate Abrasion Value Test

Mechanical Prosperities of Aggregate : Aggregate Abrasion Value

Table 3.22. Gradings of Test Samples

Sieve Size		Weight in gm. of Test Sample For Grade						
Passing	Retained on	A	B	C	D	E	F	G
mm	mm							
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	-	-	-

Mechanical Prosperities of Aggregate : Aggregate Abrasion Value

Table 3.21. Specified Abrasive Charge

Grading	*Number of spheres*	*Weight of charge (gm)*
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

Mechanical Prosperities of Aggregate : Aggregate Abrasion Value

- **At the completion of the above number of revolution, the material is discharged from the machine and a preliminary separation of the sample made on a sieve coarser than 1.7 mm IS Sieve.**
- **The difference between the original weight and the final weight of the test sample** is expressed as a percentage of the original weight of the test sample.
- **This value is reported as the percentage of wear**. The percentage of wear should not be more than 16 per cent for concrete aggregates.

DELETERIOUS MATERIALS IN AGGREGATES

BY GEET

INTRODUCTION

- WE ALL KNOW THAT "**AGGREGATE**", IS MATERIAL MAINLY USED IN CONSTRUCTION.
- IT MAY BE -SAND, GRAVEL, CRUSHED STONE, SLAG, RECYCLED CONCRETE AND GEOSYNTHETIC AGGREGATES .
- **AGGREGATES** ARE THE MOST MINED MATERIALS IN THE WORLD.
- THE AGGREGATE SERVES AS REINFORCEMENT TO ADD STRENGTH TO THE OVERALL COMPOSITE MATERIAL.

Aggregate Properties

- Shape and texture
- Soundness
- Toughness
- Absorption
- Specific gravity
- Strength and modulus
- Gradation
- Deleterious materials and cleanness
- Alkaline reactivity

WHAT IS DELETERIOUS MATERIAL

DELETERIOUS MATERIAL

-THEY ARE HARMFUL OR INJURIOUS SUBSTANCES (COATINGS) FOUND IN THE SURFACE OF THE AGGREGATE .

-THEY ARE HARMFUL TO CONCRETE PERFORMANCE.

-THESE SUBSTANCE AFFECT OR WEAKENS THE BOND B/W CEMENT & AGGREGATE AND BREAK EASILY

THEY MAY BE

- SALT
- ORGANIC IMPURITIES
- CLAY LUMPS &FRIABLE PARTICLES(EASILY CRUMBLED)
- COAL ,LIGNITE
- LIGHTWEIGHT CHERTS.

IMPACTS OF EACH TYPES ON CONCRETE PROPERTIES AND PERFORMANCE

ORGANIC IMPURITIES-

- USUALLY OF PRODUCTS OF DECAY OF VEGETABLE MATTER
- INTERFERE WITH THE PROCESS OF HYDRATION OF CEMENT.
- TO DETERMINE THE ORGANIC CONTENT OF AGGREGATE, COLORIMETRIC TEST RECOMMENDED BY ASTM.
- ASTM-INTERNATIONAL STANDARDS ORGANIZATION THAT DEVELOPS TECHNICAL STANDARDS FOR A WIDE RANGE OF MATERIALS, PRODUCTS, SYSTEMS, AND SERVICES

CLAY LUMPS AND OTHER FRIABLE PARTICLES

CLAY MAY COAT THE SURFACE OF AGGREGATES WHICH WEAKENS BOND STRENGTH BETWEEN AGGREGATE AND CEMENT PASTE.

OTHER PARTICLES MAY BE IN THE FORM OF

-SILT

-CRUSHED DUST

IMPACTS ON CONCRETE

1.LOW WEAR RESISTANCE

2. REDUCE DURABILITY

3. MAY RESULT POPOUTS

LIGNITE AND COAL

THESE MATERIALS MAY

1. RESULT STRAINING ON CONCRETE

2. CAUSE POPOUTS

3. AIR ENTRAPMENT

LIGNITE

COAL

STARIN

AIR PORES

SALT PARTICLES

SAND FROM SEASHORE OR A RIVER , AS WELL AS DESERT SAND CONTAINS SALT.

IMPACTS -

1. REINFORCEMENT *CORROSION*
2. ABSORB MOISTURE AND CAUSE EFFLORESCENCE

EFFLORESCENCE

CORROSION

LIGHTWEIGHT CHERT

- CHERT IS A MICROCRYSTALLINE SEDIMENTARY ROCK MATERIAL COMPOSED OF SILICON DIOXIDE (SiO_2)

- LIGHTWEIGHT MEANS HAVING SPECIFIC GRAVITY OF LESS THAN 2.40.

CHERT

THEY MAY RESULT

1. REDUCED DURABILITY

2. POPOUTS


builderbill

Alkali-silica reaction (ASR)

Alkali Silica Reaction Damage in Bridge

Internal Sulphate Attack
Damage to Precast Beams

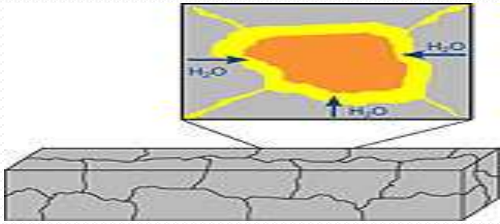
Corrosion Damage to Highway Bridge Column

ALKALI SILICA REACTION (ASR)

- ✓A chemical reaction develops between the reactive silica contained in the aggregates and the alkalis (Na_2O and K_2O) within the cement paste known as Alkali-Silica Reaction.

- ✓ASR also known as "Concrete Cancer"

INTRODUCTION



In most concrete, aggregates are more or less chemically inert. However, some aggregates react with the alkali hydroxides in concrete, causing expansion and cracking over a period of many years. This alkali-aggregate reaction has two forms—**alkali-silica reaction (ASR)** and alkali-carbonate reaction (ACR).

ASR is the **most common** form of alkali-aggregate reaction (AAR) in concrete.

How ASR takes place…..???

Alkali-silica reaction is one of the most recognized deleterious phenomena in concrete.

Various types of silica present in aggregates react with the hydroxyl ions present in the pore solution in concrete. The silica, now in solution, reacts with the sodium (Na+) and potassium (K+) alkalis to form a volumetrically unstable alkali silica gel.

Water absorbed by the gel can be water not used in the hydration reaction of the cement,

- free water from rain,
- snowmelt,
- rivers
- water condensed from air moisture.

ADVERSE EFFECTS OF ASR

- ✓The reaction is followed by expansion / swelling of the aggregate particles due to the formation of alkali-silicate gel that absorbs water and tends to increase in volume. Since the gel is confined by the cement paste, it builds up pressure causing expansion, due to which multidirectional cracking (map cracking) appears on surface of concrete.

In general, the reaction can be viewed as a two-step process :

Step 1:

- *Silica + alkali $\longrightarrow$ alkali-silica gel (sodium silicate)*
- *$SiO_2 + 2NaOH + H_2O \longrightarrow Na_2SiO_3.2H_2O$ (2KOH can replace 2NaOH)*

Step 2

Gel reaction product + water → *expansion*

Since the gel is restrained by the surrounding mortar, an internal pressure is generated by the swelling. Once that pressure is larger than the tensile strength of the concrete, cracks occur leading to additional water migration or absorption and additional gel swelling.

Conditions required for ASR…..

The conditions required for ASR to occur are:

- A sufficiently high alkali content of the cement (or alkali from other sources)
- A reactive aggregate, such as chert
- Water - ASR will not occur if there is no available water in the concrete, since alkali-silica gel formation requires water.

SYMPTOMS OF ASR

- √ Visual examination of those concrete structures that are affected will generally show :-
  - ➢ map or pattern cracking
  - ➢ a general appearance that indicates that the concrete is swelling.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ASR MITIGATION MEASURES

Preventing deleterious expansions caused by the alkali-silica reaction can be achieved by

1. Limiting moisture
2. Selecting Non-Reactive Aggregates
3. Minimizing Alkalis
4. Mineral Admixtures
5. Chemical Admixtures
6. Air Entrainment

1. <u>Limiting moisture:</u>

- The alkali-silica reaction will not take place in a concrete structure if the internal relative humidity of the concrete is lower than 80%.
- As a result, keeping the concrete dry will prevent the reaction from occurring. However, this is practically impossible for exterior structures.
- Lowering the permeability of concrete by reducing the water-cement ratio reduces the internal moisture and delays the reaction. However, a low water-cement ratio results in a higher cement content, higher alkali content, and a reduced pore space which could lead to higher expansions .

1. Limiting moisture:

- Lowering the permeability of concrete using mineral admixtures is a more workable approach to reduce the deleterious effects of ASR.
- Applying a protective coating to concrete is a good solution provided that the coating is correctly installed. Because of the high cost of concrete coatings, this method has been used on a limited basis.

2. Selecting Non-Reactive Aggregates:

Using a non-reactive aggregate in concrete and avoiding reactive aggregates will prevent ASR damage. This demands an accurate testing correctly predicting the ASR reactivity of aggregates.

Such tests exist but need more refining and improvements . This is not economical in some regions where all locally available aggregates are considered reactive.

3. Minimizing Alkalis:

- The most commonly used mitigation method is to control the alkali content in the concrete.
- Cement is the major source of alkali in the concrete. Alkalis are also provided, in smaller amounts, from fly ash, mixing water, chemical admixtures, aggregates, and external sources such as seawater.
- Controlling the alkali content of the cement has been proved to decrease the expansions caused by ASR. A proposed limit of 0.60% has been recommended for the alkali content of cement to be used in concrete to reduce ASR expansions.

4. Mineral Admixtures:

Ever since the alkali-silica reaction was discovered, researchers have reported on the effectiveness of mineral admixtures in reducing its deleterious effects on concrete.

Effective mineral admixtures include fly ash, silica fume, ground granulated slag, and calcined clay reduce ASR expansions by one or more of the following mechanisms:

1. Reducing the alkali content of the concrete mix.
2. Reducing the pH of the concrete pore solution.
3. Consuming the calcium hydroxide, which might result in lower swelling.
4. Reducing concrete permeability.

ASR test…..

- *The concrete microbar test was proposed by Grattan-Bellew et al. (2003) as a universal accelerated test for alkali-aggregate reaction.*
- The Portland Cement Association recommends analyzing the aggregate according to *ASTM C 295,* "Standard Guide for Petrographic Examination of Aggregates for Concrete

If the aggregate contains more than the following quantities of any of these reactive minerals, it is considered potentially reactive:

- *Optically strained, microfractured, or microcrystalline quartz exceeding 5.0%*
- *Chert or chalcedony exceeding 3.0%*
- *Tridymite or crystobalite exceeding 1.0%*
- *Opal exceeding 0.5%*
- *Natural volcanic glass in volcanic rocks exceeding 3.0%*

Test Methods for Alkali-Silica Reactivity

- *ASTM C 227,*
  Potential alkali-reactivity of cement-aggregate combinations (mortar-bar method)
- *ASTM C 289,*
  Potential alkali-silica reactivity of aggregates
- *ASTM C 294,*
  Constituents of natural mineral aggregates
- *ASTM C 295,*
  Petrographic examination of aggregates for concrete

CEMENT:

Chemical Composition of Portland Cement

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding. Table shows the approximate oxide composition limits of ordinary Portland cement.

Approximate Oxide Composition Limits of Ordinary Portland Cement

Oxide	Per cent content
CaO	60–67
SiO_2	17–25
Al_2O_3	3.0–8.0
Fe_2O_3	0.5–6.0
MgO	0.1–4.0
Alkalies (K_2O, Na_2O)	0.4–1.3
SO_3	1.3–3.0

The identification of the major compounds of cement is largely based on Bogue's equations and hence it is called "**Bogue's Compounds**". The four compounds usually regarded as major compounds are listed in table

Major compounds of cement

Name of Compound	Formula	Abbreviated Formula
Tricalcium silicate	$3\ CaO.SiO_2$	C_3S
Dicalcium silicate	$2\ CaO.SiO_2$	C_2S
Tricalcium aluminate	$3\ CaO.Al2O_3$	C_3A
Tetracalcium aluminoferrite	$4\ CaO.Al_2O_3.Fe_2O_3$	C_4AF

It is to be noted that for simplicity's sake abbreviated notations are used.

C stands for CaO

S stands for SiO_2

A for Al_2O_3

F for Fe_2O_3

H for H_2O

HYDRATION OF CEMENT

The Chemical reaction that takes place between cement and water is called as hydration of cement. This reaction is exothermic in nature, due to which considerable amount of heat is released during hydration of cement. This is called as 'heat of hydration'. The hydration of cement is not a sudden process. This reaction is faster in early period and continues indefinitely at a decreasing rate

What Happens During Hydration of Cement

During hydration of cement, C3S and C2S react with water and calcium silicate hydrate (C-S-H) is formed along with calcium hydroxide $Ca(OH)_2$.

- 2 C3S + 6H → C3S2H3 + 3 $Ca(OH)_2$
- 2 C2S + 4H → C3S2H3 + $Ca(OH)_2$

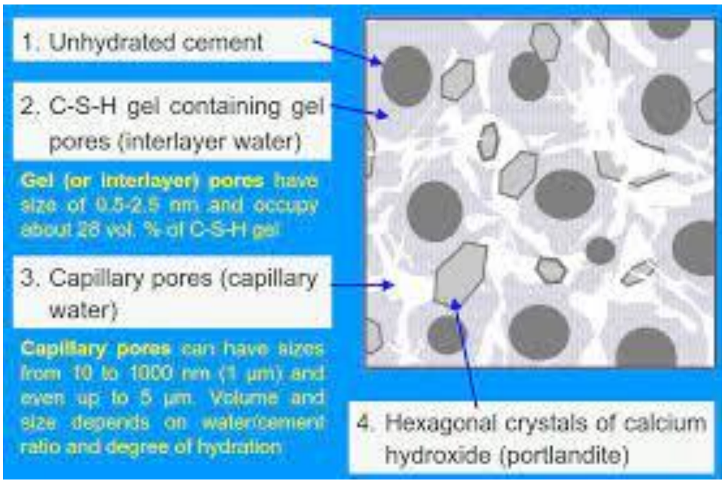
- Calcium silicate hydrate is one of the most important product of hydration process and it determines the good properties of cement. It can be seen from the above reactions that C_3S produces more quantity of calcium hydroxide than C_2S.
- Calcium hydroxide is not a desirable product in concrete mass as it is soluble in water and gets leached out thereby making the concrete porous, particularly in hydraulic structures, thus decreasing the durability of concrete.
- Calcium hydroxide also reacts with sulphates present in water and soils to form calcium sulphate which further reacts with C_3A and causes deterioration of concrete. This process is known as Sulphate Attack. The only advantage of calcium hydroxide is that, being alkaline in nature it maintains a high pH value in concrete which resists the corrosion of reinforcement.
- It has been estimated that on an average 23% of water by weight of cement is required for chemical reaction with Portland cement compounds. As this 23% of water chemically combines with cement, it is called as bound water.
- A certain quantity of water is absorbed by the gel pores. This water is known as gel water. The bound water and gel water are complementary to each other. It has been estimated that 15% water by weight of cement is required to fill up the gel pores.
- Therefore, a total of 38% of water by weight of cement is required for the complete chemical reaction of cement and occupy the space within gel pores. If water equal to 38% by weight of cement is only used then it can be noticed that the resultant paste

will undergo full hydration and no extra water will be available for the formation of undesirable capillary cavities.

STRUCTURE OF HYDRATED CEMENT

The desirable engineering characteristics of hardened concrete —strength, dimensional stability, and durability —are influenced not only by the proportion but also by the properties of the hydrated cement paste, which, in turn, depend on the microstructural features (i.e., the type, amount, and distribution of solids and voids)

Fresh cement paste is a plastic network of particles of cement in water but, once the cement paste has set, its apparent or gross volume remains approximately constant. At any stage of hydration, the hardened paste consists of hydrates of the various compounds, referred to collectively as gel, crystals of Ca(OH)2, some minor components, un-hydrated cement and the residue of water-filled spaces in the fresh paste, two distinct classes of pores represented diagrammatically in the following figure.



- **<u>Different Types and Grades of Cement</u>**

The basis of every construction depends upon the various raw materials that are used. The composition and strength of cement is a very essential part to pay lot of attention too. There are a wide variety of cements which are available and each of these hold applications in different places and purposes.

There are different grades of cements which are available in the market and each of them offer an advantage of its own. So, here listed is a brief of the various types of cement and grades available.

- **Ordinary Portland**
  Known as the most common type of cement this is widely used in residential construction. The cement is a mixture of limestone with clay that forms clinker which is then finely crushed to for this grey color cement.
- **Rapid Hardening**
  This attains good strength in the early days and is usually used in concrete where the formworks will be removed in the early days This is similar to Ordinary Portland cement(OPC) and has higher limestone content. The strength attained in 3 days is similar to that of what OPC attains in 7days and saves cost of formwork. It is used in concrete construction, roadways etc,.
- **Quick setting :**
  Used especially in Static or running water, this sets quickly compared to rapid hardening which gains strength quickly. The rate of gain of strength in this case is quite similar to that of OPC
- **White Cement**
  This is prepared free of Iron Oxide and is a type of OPC in white color. It is used for various decorative work inside and outside homes and is comparatively costlier. Its used for facing slabs, paths of garden etc,.
- **Coloured cement**
  Again, it is used for decorative constructions and has about 5-10% mineral pigments added to normal cement.
- **Low Heat**
  This cement is widely used in applications where cracking of cement due to heat needs to be avoided. The low heat of hydration coming from keeping tricalcium aluminate percentage below 6 helps in avoiding the cracking. This cement is less reactive although has a higher settling time compared to OPC. It is used in Dams and marine construction extensively.
- **Expansive**
  This cement adds volume once gets settled and is widely used to avoid concrete shrinkage. It is used in hydraulic structures as well as for repair works where we need to bon with old concrete surface.
- **Air Entraining Cement**
  It is produced by a mixture of air entraining agent and is used to fill up gaps caused during casting where excess amount of water might have been used.
- **Hydrophobic**
  As the name suggests the cement helps with providing resistance to structures in areas which are wet for prolonged durations.
- **Portland Pozzolana**

This cement is especially preferred for applications which need strength for ages and gains great compressive strength with age unlike other cement types. It is used In construction of dams etc.

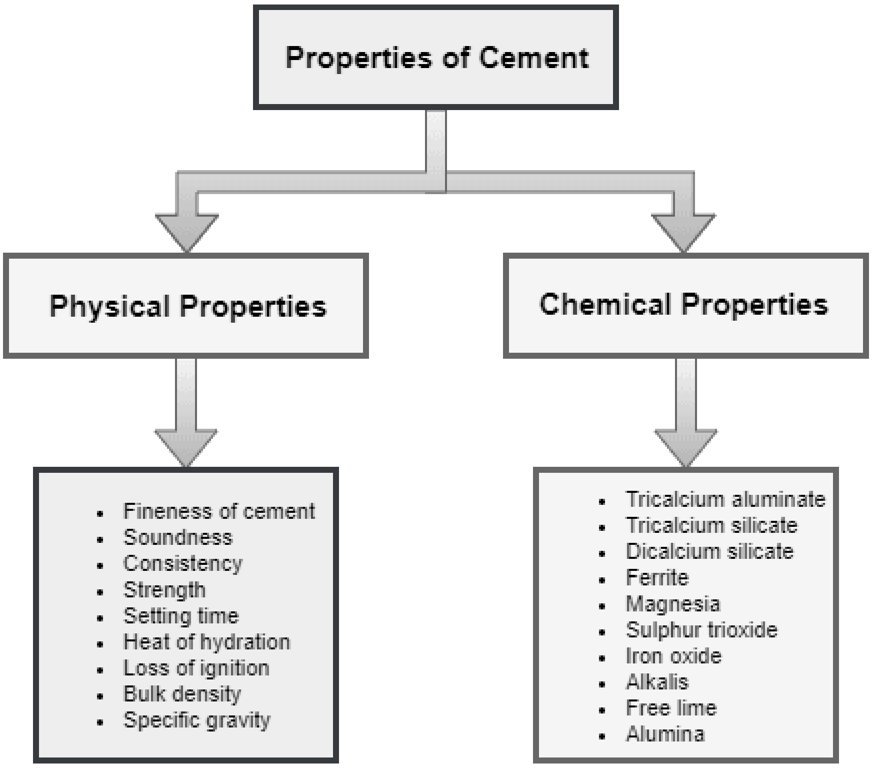
- **Grade of Cement**

There are about 3 grades of cement available in the market. The grade is determined on the basis of compressive strength attained in 28 days.

- **33- Grade OPC**
  Commonly used for constructions in normal environmental conditions, the compression here is 33N/mm^2 under standard conditions.
- **43- Grade OPC**
  This shows a compression of 43N/mm^2 and is commonly used for plain concrete work and plastering.
- **53- Garde OPC**
  This gives a compression of 53 N/mm^2 and is not used in common contrition. It is used as a reinforces cement concrete for structural purposes.

PHYSICAL AND CHEMICAL PROPERTIES OF CEMENT

Cement, a popular binding material, is a very important civil engineering material.



Physical Properties of Cement

Different blends of cement used in construction are characterized by their physical properties. Some key parameters control the quality of cement. The physical properties of good cement are based on:

- Fineness of cement
- Soundness
- Consistency
- Strength
- Setting time
- Heat of hydration
- Loss of ignition
- Bulk density
- Specific gravity (Relative density)

These physical properties are discussed in details in the following segment. Also, you will find the test names associated with these physical properties.

Fineness of Cement

The size of the particles of the cement is its fineness. The required fineness of good cement is achieved through grinding the clinker in the last step of cement production process. As hydration rate of cement is directly related to the cement particle size, fineness of cement is very important.

Soundness of Cement

Soundness refers to the ability of cement to not shrink upon hardening. Good quality cement retains its volume after setting without delayed expansion, which is caused by excessive free lime and magnesia.

Tests:

Unsoundness of cement may appear after several years, so tests for ensuring soundness must be able to determine that potential.

- **Le Chatelier Test**
  This method, done by using Le Chatelier Apparatus, tests the expansion of cement due to lime. Cement paste (normal consistency) is taken between glass slides and submerged in water for 24 hours at 20+1°C. It is taken out to measure the distance between the indicators and then returned under water, brought to boil in 25-30 mins and boiled for an hour. After cooling the device, the distance between indicator points is measured again. In a good quality cement, the distance should not exceed 10 mm.

- **Autoclave Test**
  Cement paste (of normal consistency) is placed in an autoclave (high-pressure steam vessel) and slowly brought to 2.03 MPa, and then kept there for 3 hours. The change in length of the specimen (after gradually bringing the autoclave to room temperature and pressure) is measured and expressed in percentage. The requirement for good quality cement is a maximum of 0.80% autoclave expansion.
  Standard autoclave test: AASHTO T 107 and ASTM C 151: Autoclave Expansion of Portland Cement.

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It is measured by Vicat Test.

In Vicat Test Cement paste of normal consistency is taken in the Vicat Apparatus. The plunger of the apparatus is brought down to touch the top surface of the cement. The plunger will penetrate the cement up to a certain depth depending on the consistency. A cement is said to have a normal consistency when the plunger penetrates 10±1 mm.

Strength of Cement

Three types of strength of cement are measured – compressive, tensile and flexural. Various factors affect the strength, such as water-cement ratio, cement-fine aggregate ratio, curing conditions, size and shape of a specimen, the manner of moulding and mixing, loading conditions and age. While testing the strength, the following should be considered:

- Cement mortar strength and cement concrete strength are not directly related. Cement strength is merely a quality control measure.
- The tests of strength are performed on cement mortar mix, not on cement paste.
- Cement gains strength over time, so the specific time of performing the test should be mentioned.

Compressive Strength

It is the most common strength test. A test specimen (50mm) is taken and subjected to a compressive load until failure. The loading sequence must be within 20 seconds and 80 seconds.

Standard tests:

i. ASTM C 109: Compressive Strength of Hydraulic Cement Mortars (Using 50-mm or 2-in. Cube Specimens)
ii. ASTM C 349: Compressive Strength of Hydraulic Cement Mortars (Using Portions of Prisms Broken in Flexure)

Tensile strength

Though this test used to be common during the early years of cement production, now it does not offer any useful information about the properties of cement.

Flexural strength

This is actually a measure of tensile strength in bending. The test is performed in a 40 x40 x 160 mm cement mortar beam, which is loaded at its centre point until failure.

Standard test:

i. ASTM C 348: Flexural Strength of Hydraulic Cement Mortars

Setting Time of Cement

Cement sets and hardens when water is added. This setting time can vary depending on multiple factors, such as fineness of cement, cement-water ratio, chemical content, and admixtures. Cement used in construction should have an initial setting time that is not too low and a final setting time not too high. Hence, two setting times are measured:

- **Initial set:** When the paste begins to stiffen noticeably (typically occurs within 30-45 minutes)
- **Final set:** When the cement hardens, being able to sustain some load (occurs below 10 hours)

Again, setting time can also be an indicator of hydration rate.

Standard Tests:

i. AASHTO T 131 and ASTM C 191: Time of Setting of Hydraulic Cement by Vicat Needle

Heat of Hydration

When water is added to cement, the reaction that takes place is called hydration. Hydration generates heat, which can affect the quality of the cement and also be beneficial in maintaining curing temperature during cold weather. On the other hand, when heat generation is high, especially in large structures, it may cause undesired stress. The heat of hydration is affected most by C_3S and C_3A present in cement, and also by water-cement ratio, fineness and curing temperature. The heat of hydration of Portland cement is calculated by determining the difference between the dry and the partially hydrated cement (obtained by comparing these at 7th and 28th days).

Standard Test:

ASTM C 186: Heat of Hydration of Hydraulic Cement

Loss of Ignition

Heating a cement sample at 900 - 1000°C (that is, until a constant weight is obtained) causes weight loss. This loss of weight upon heating is calculated as loss of ignition. Improper and prolonged storage or adulteration during transport or transfer may lead to pre-hydration and carbonation, both of which might be indicated by increased loss of ignition.

Standard Test:

ASTM C 114: Chemical Analysis of Hydraulic Cement

Bulk density

When cement is mixed with water, the water replaces areas where there would normally be air. Because of that, the bulk density of cement is not very important. Cement has a varying range of density depending on the cement composition percentage. The density of cement may be anywhere from 62 to 78 pounds per cubic foot.

Specific Gravity (Relative Density)

Specific gravity is generally used in mixture proportioning calculations. Portland cement has a specific gravity of 3.15, but other types of cement (for example, portland-blast-furnace-slag and portland-pozzolan cement) may have specific gravities of about 2.90.

Standard Test:

ASTM C 188: Density of Hydraulic Cement

Chemical Properties of Cement

The raw materials for cement production are limestone (calcium), sand or clay (silicon), bauxite (aluminum) and iron ore, and may include shells, chalk, marl, shale, clay, blast furnace slag, slate. Chemical analysis of cement raw materials provides insight into the chemical properties of cement.

1. **Tricalcium aluminate (C3A)**
   Low content of C3A makes the cement sulfate-resistant. Gypsum reduces the hydration of C_3A, which liberates a lot of heat in the early stages of hydration. C3A does not provide any more than a little amount of strength.
   Type I cement: contains up to 3.5% SO_3 (in cement having more than 8% C_3A)
   Type II cement: contains up to 3% SO_3 (in cement having less than 8% C_3A)

2. **Tricalcium silicate (C_3S)**
   C3S causes rapid hydration as well as hardening and is responsible for the cement's early strength gain an initial setting.

3. **Dicalcium silicate (C_2S)**
   As opposed to tricalcium silicate, which helps early strength gain, dicalcium silicate in cement helps the strength gain after one week.

4. **Ferrite (C_4AF)**
   Ferrite is a fluxing agent. It reduces the melting temperature of the raw materials in the kiln from 3,000°F to 2,600°F. Though it hydrates rapidly, it does not contribute much to the strength of the cement.

5. **Magnesia (MgO)**
   The manufacturing process of Portland cement uses magnesia as a raw material in dry process plants. An excess amount of magnesia may make the cement unsound and expansive, but a little amount of it can add strength to the cement. Production of MgO-based cement also causes less CO2 emission. All cement is limited to a content of 6% MgO.

6. **Sulphur trioxide**
   Sulfur trioxide in excess amount can make cement unsound.

7. **Iron oxide/ Ferric oxide**
   Aside from adding strength and hardness, iron oxide or ferric oxide is mainly responsible for the color of the cement.

8. **Alkalis**
   The amounts of potassium oxide (K_2O) and sodium oxide (Na_2O) determine the alkali content

of the cement. Cement containing large amounts of alkali can cause some difficulty in regulating the setting time of cement. Low alkali cement, when used with calcium chloride in concrete, can cause discoloration. In slag-lime cement, ground granulated blast furnace slag is not hydraulic on its own but is "activated" by addition of alkalis. There is an optional limit in total alkali content of 0.60%, calculated by the equation $Na_2O + 0.658\ K_2O$.

9. **Free lime**
   Free lime, which is sometimes present in cement, may cause expansion.

10. **Silica fumes**
    Silica fume is added to cement concrete in order to improve a variety of properties, especially compressive strength, abrasion resistance and bond strength. Though setting time is prolonged by the addition of silica fume, it can grant exceptionally high strength. Hence, Portland cement containing 5-20% silica fume is usually produced for Portland cement projects that require high strength.

11. **Alumina**
    Cement containing high alumina has the ability to withstand frigid temperatures since alumina is chemical-resistant. It also quickens the setting but weakens the cement.

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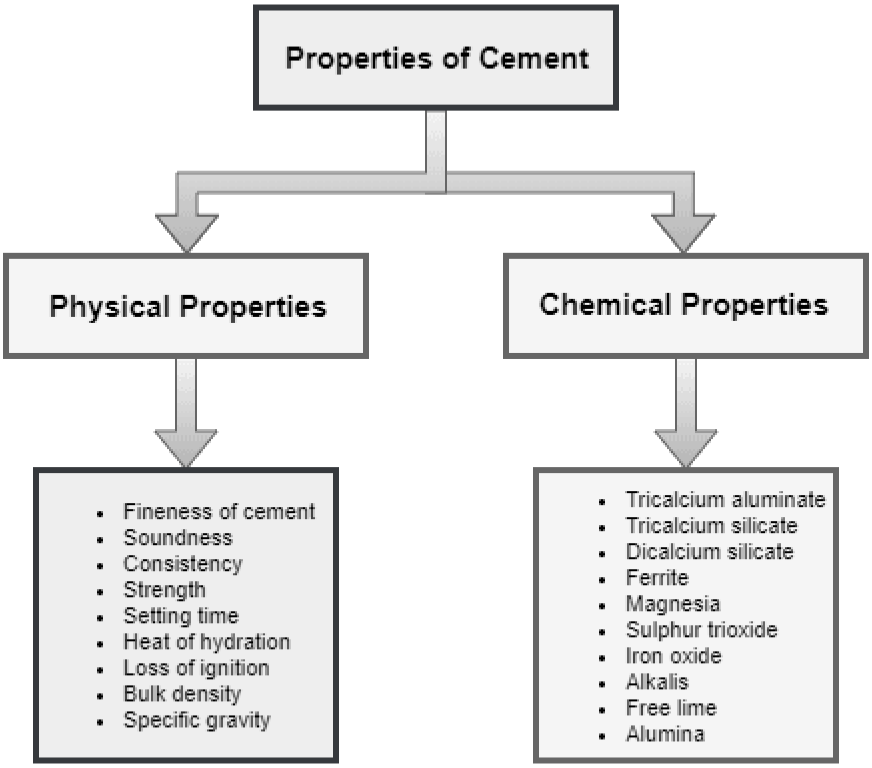

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