Notes for UNIT-II (Aggregates used for concrete making)

Concrete The Extensively used material after water because of the following reasons

- Versatile
- Pliable when mixed
- Strong & Durable
- Does not Rust or Rot
- Does Not Need a Coating
- Resists Fire
- Almost Suitable for any Environmental Exposure Conditions

Concrete is a Rocklike Material

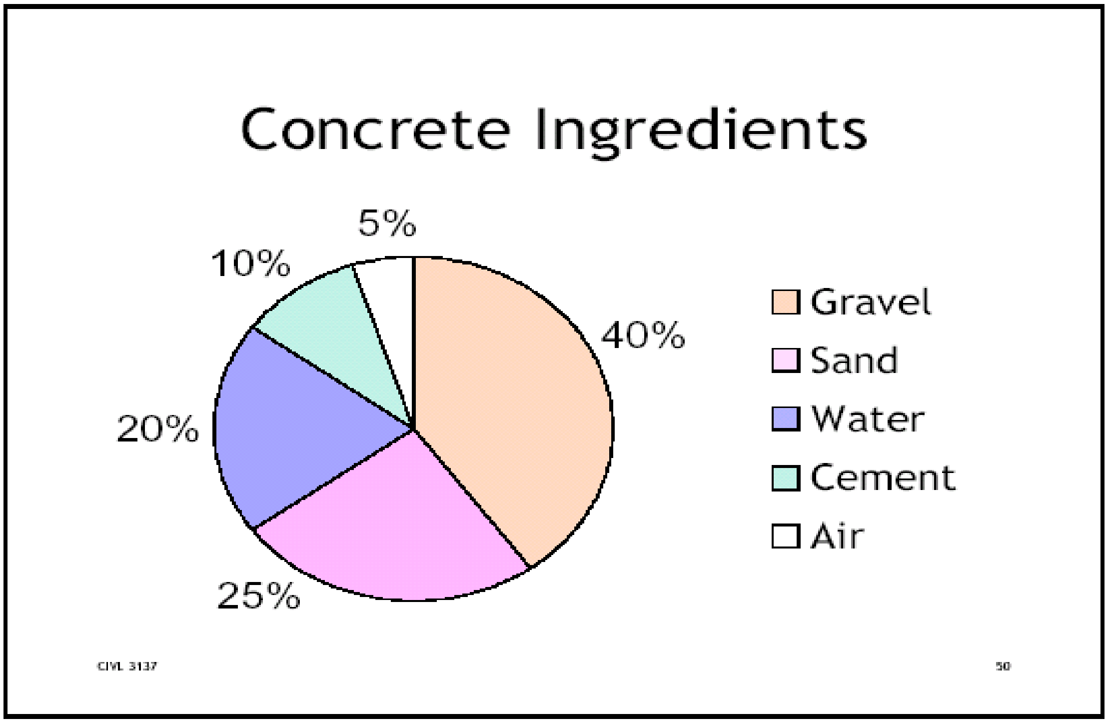
- Ingredients
  - Portland Cement
  - Coarse Aggregate
  - Fine Aggregate
  - Water

Admixtures (optional)

Table Showing the diverse nature of the ingredients of the concrete

Ingredient	Size	Shape	Specific Gravity	Texture
Cement	**50 microns Average Particle size**	**Nearly Spherical**	**3.00 to 3.20**	**Smooth**
Coarse Aggregtes	**80mm - 4.75mm**	**Round, Angular, cuboidal, rounded, flaky, elongated**	**2.6-2.8**	**Glassy, Smooth, Granular, Crystalline, Honeycombed and porous**
Fine Aggregates	**4.75mm-150μ**	**Angular or rounded**	**2.5-2.6**	**Smooth,Granular**
Water	**-**	**-**	**1.0**	**-**
Mineral Admixtures	**<40 microns Average Size**	**Nearly Spherical**	**Varies**	**Glassy, smooth**

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

Aggregates are classified as below:
Based on

- **size:-** F.A & C.A.
- **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.

There are two types of Aggregates used in concrete making based on their size:

- Coarse Aggregates.
- Fine Aggregates.

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.

Rock and Mineral Constituents in Aggregates

1.**Minerals**

- Silica

  Quartz, Opal
- Silicates

  Feldspar, Clay
- Carbonate

  Calcite, DolomiteSulfate

  Sulfate

  Gypsum, Anhydrite

  Iron sulfide

  Pyrite, Marcasite

  Iron oxide

  Magnetite, Hematite

2.**Igneous rocks**

- Granite
- Syenite
- Diorite
- Gabbro
- Peridotite
- Pegmatite
- Volcanic glass
- Felsite
- Basalt

3. **Sedimentary rocks**

- Conglomerate
- Sandstone
- Claystone, siltstone, argillite, and shale
- Carbonates
- Chert

4. **Metamorphic rocks**

- Marble
- Metaquartzite
- Slate

- Phyllite
- Schist

Normal-Weight Aggregate

Most common aggregates

- 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

- Pumice
- Scoria
- Perlite
- Vermiculite
- Diatomite

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

Heavyweight Aggregate

- Barite
- Limonite
- Magnetite
- Ilmenite
- Hematite
- Iron
- Steel punchings or shot

Produce high-density concrete up to 6400 kg/m^3
Used for Radiation Shielding

Aggregate Characteristics

Grading of Aggregates

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.
Coarse aggregate—5 sieves with openings from 4.75mm to 80 mm.

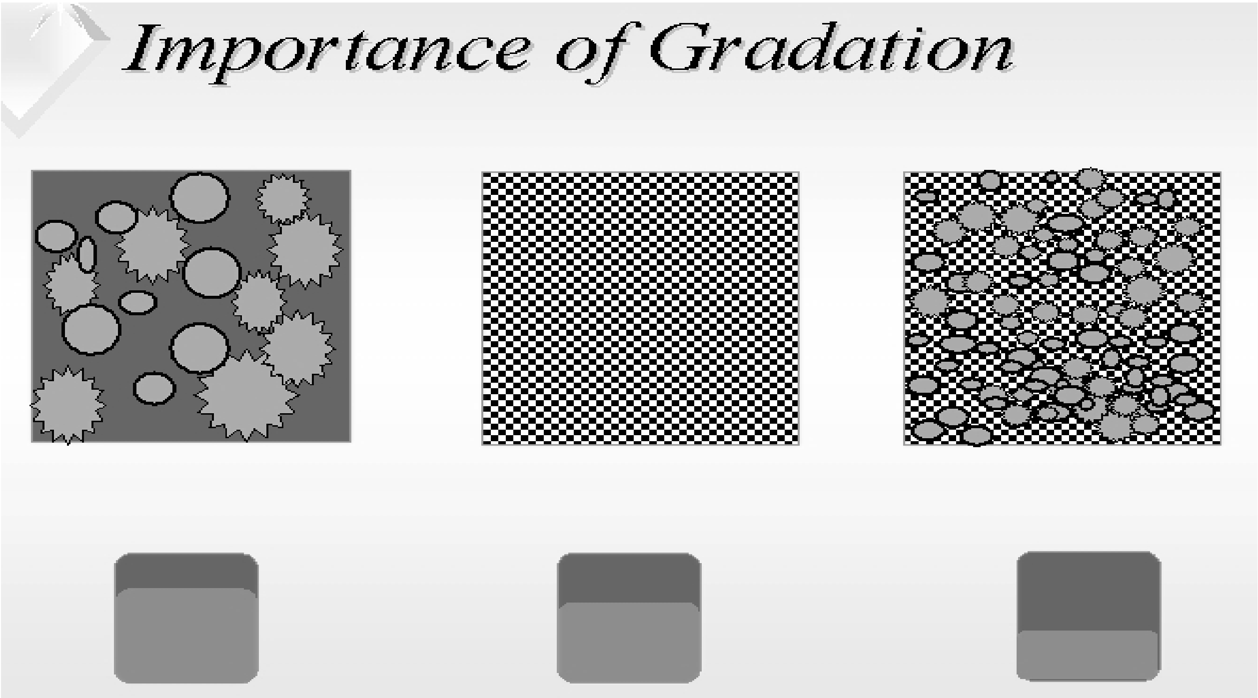
Gradation (grain size analysis)
Grain size distribution for concrete mixes that will provide a dense strong mixture.
Ensure that the voids between the larger particles are filled with medium particles. The remaining voids are filled with still smaller particles until the smallest voids are filled with a small amount of fines.
Ensure maximum density and strength using a maximum density curve

Good Gradation

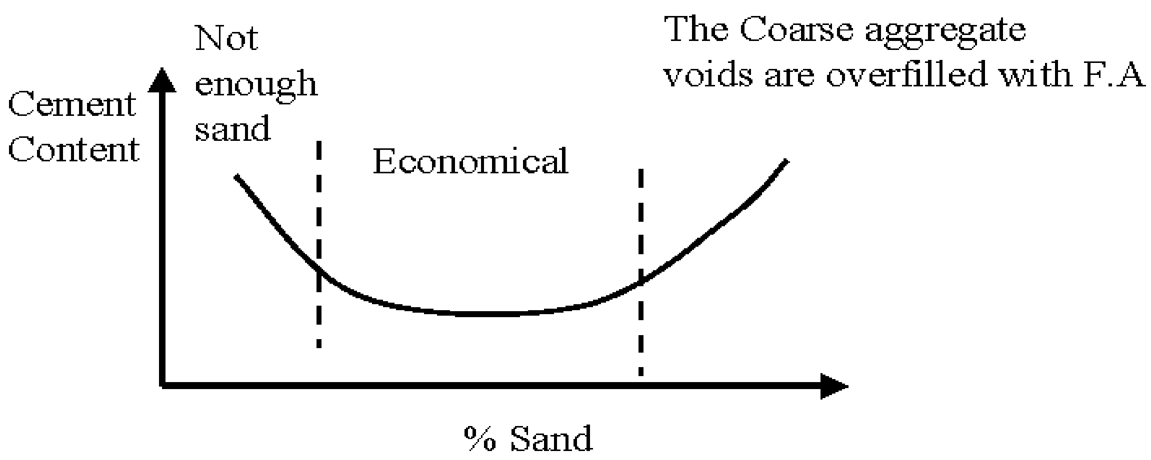
Concrete with good gradation will have fewer voids to be filled with cement paste (🡩 economical mix)
Concrete with good gradation will have fewer voids for water to permeate (🡩 durability)
Particle size distribution affects:

- Workability
- Mix proportioning
- Freeze-thaw resistance (🡩 durability)

Range of Particle Sizes



Significance of Grading



Fine-Aggregate Grading Limits
IS -383

IS Sieve Designation	Percentage passing by weight Grading			
	Zone-I (Coarse Sand)	Zone-II Most Suitable/Desirable	Zone-III	Zone-IV (Fine Sand)
10mm	100	100	100	100
4.75mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-100	85-100	95-100
1.18mm	30-70	55-90	75-100	90-100
600µm	15-34	35-59	60-79	80-100
300µm	5-20	8-30	12-40	15-50
150µm	0-10	0-10	0-10	0-15
Fineness Modulus	4.0-2.71	3.37-2.10	2.78-1.71	2.25-1.35

The percentage passing **600µm** sieve will decide the zone of the sand.
Zone-I Coarse Sand
Zone-II
Zone-III
Zone-IV Fine Sand

Grading Limits Can also be represented through a graph of sieve size on the x-axis and % passing on the Y-axis (Semi log sheet).

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 specified sieves are: 150 µm (No. 100), 300 µm (No. 50), 600 µm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8), 4.75 mm (No. 4), 9.5 mm , 19.0 mm , 37.5 mm , 75 mm , and 150 mm.

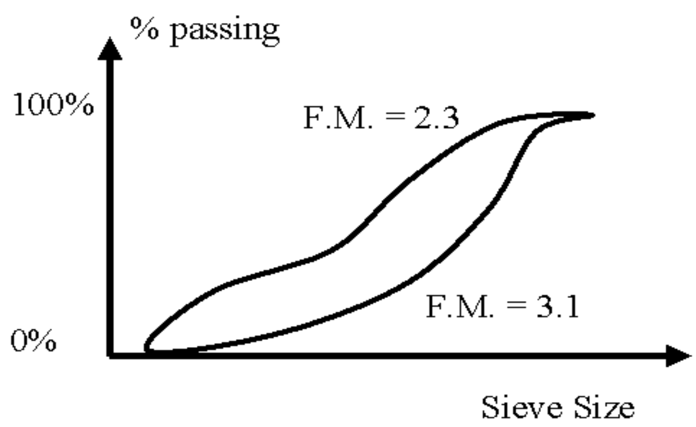
Results of Sieve Analysis and calculation of FM of Sand

Sieve size	Percentage of individual fraction retained, by mass	Percentage passing, by mass	Cumulative percentage retained, by mass
10 mm	0	100	0
4.75 mm	2	98	2
2.36 mm	13	85	15
1.18 mm	20	65	35
600 µm	20	45	55
300 µm	24	21	79
150 µm	18	3	97
Pan	3	0	—
Total	100		283

Fineness modulus = 283 ÷ 100 = 2.83

- Index of fineness of an aggregate.
- The fineness modulus of the fine aggregate is required for mix design since sand gradation has the largest effect on workability. A fine sand (low FM) has much higher effect paste requirements for good workability.
- The FM of the coarse aggregate is not required for mix design purposes.

- It is computed by adding the cumulative percentages of aggregate retained on each of the specified series of sieves, and dividing the sum by 100 [smallest size sieve: No. 100 (150 μm)].



For concrete sand, FM range is 2.3 to 3.1

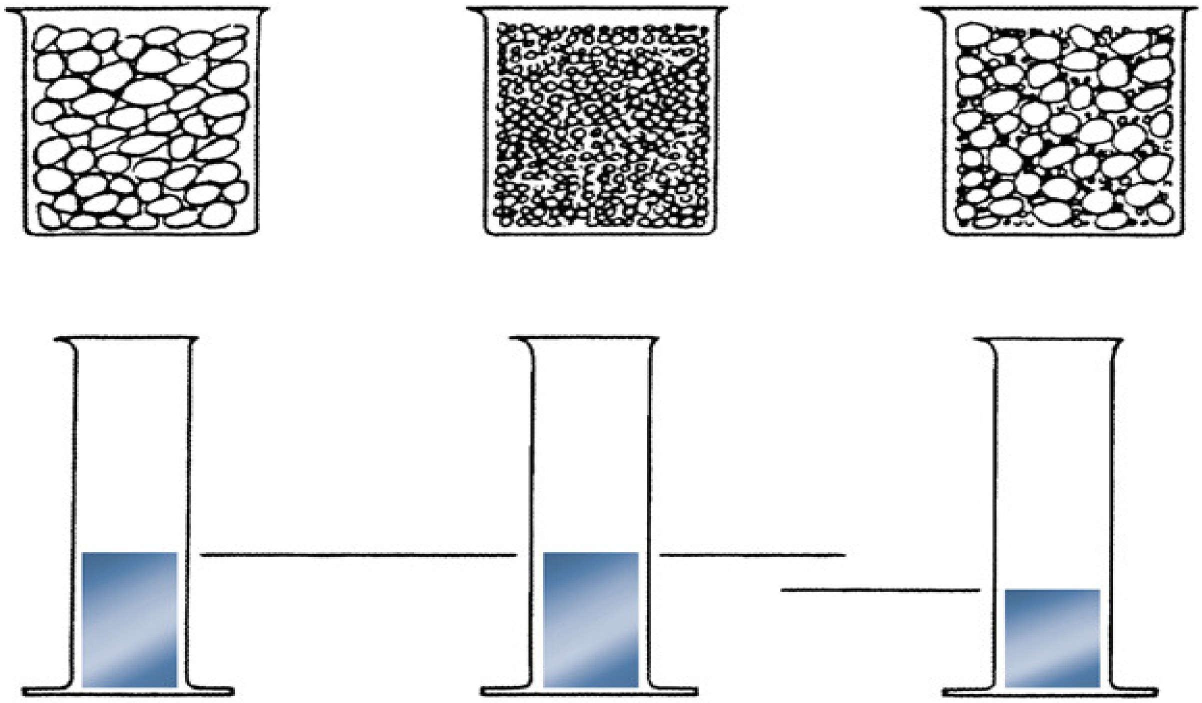
- Note: The higher the FM, the coarser the aggregate.

- It is important to note that the fineness modulus is just one number which only characterizes the average size of the aggregate, and different grading may have the same fineness modulus.

Fine Aggregate effect on concrete

- Oversanded (More than required sand)
  - Over cohesive mix.
  - Water reducers may be less effective.
  - Air entrainment may be more effective.
- Undersanded (deficit of sand)
  - Prone to bleed and segregation.
  - May get high levels of water reduction.
  - Air entrainers may be less effective.
- Sand grading
  - gap graded or single sized may enhance bleed and segregation. Air entrainment may help fill the gaps.
- Coarse aggregate
  - Poor grading may give a harsh mix at low workabilities and segregation at high workabilities.
  - Effect on admixtures is small.
  - Elongated or flaky aggregates may cause workability difficulties .

Reduction of Voids



If uniform size aggregates are there there will be more voids as can be seen from the first two figures.If properly graded aggregates are used which contain suitable percentage of all size then the voids will be minimum which is explained in the figure.

Maximum Size vs. Nominal Maximum Size of Aggregate

Maximum size — is the smallest sieve that all of a particular aggregate must pass through.
Nominal maximum size — is the standard sieve opening immediately smaller than the smallest through which all of the aggregate must pass.

The nominal maximum-size sieve may retain 5% to 15%

Nominal Maximum Size of Aggregate

Size should not exceed —

- 1/5 of the narrowest dimension between sides of forms.
- 3/4 clear spacing between rebars and between rebars and the form.
- 1/3 depth of slabs.

Higher maximum aggregate size lowers paste requirements, increases strength and reduces w/c ratio. Excessively large aggregates reduce strength due to reduced surface area for bonding. It affects the paste requirements, optimum grading depends on MSA and nominal max. size. The higher MSA, the lower the paste requirements for the mix. Aggregate size affects the following concrete properties: water demand, cement content, microcracking (strength).

Effect of aggregate size on the surface area

size	# of particles	volume	surface area
1"	1	1 cubic inch	6 square inches
.5"	8	1 cubic inch	12 square inches
0.25	64	1 cubic inch	24 square inches
0.125	512	1 cubic inch	48 square inches

Larger particles, less surface area, thicker coating, easy sliding of particles. Smaller particles, more surface area, thinner coating, interlocking of particles

Maximum Aggregate Size and Water Requirement

Effect on water demand

Max size of Aggregate	Slump 30 - 60 mm	Slump 60 - 180 mm
10 mm	230 kg/m^3	250 kg/m^3
20 mm	210 kg/m^3	225 kg/m^3
40 mm	190 kg/m^3	205 kg/m

Effect on cement content at constant w/c of 0.60

Max size of aggregate	Water content	Cement content	A:C ratio
10 mm	230 kg/m^3	380 kg/m^3	4.7
20 mm	210 kg/m^3	350 kg/m^3	5.3
40 mm	190 kg/m^3	315 kg/m^3	6.0

In general the grading and maximum size of aggregate affect the following:

- Relative aggregate proportions (i.e. FA/CA and FA/TA ratios)
- Cement and water requirements
- Workability and pumpability of fresh concrete: very coarse sands and coarse aggregate can produce harsh, unworkable mixes
- Uniformity of concrete from batch to batch
- Porosity, shrinkage, and durability of hardened concrete
- Economy in concrete production: very fine sands are often uneconomical

Moisture In Aggregates

Aggregates have two types of moisture:

1. Absorbed moisture – retained in pores
2. Surface moisture – water attached to surface

Aggregates have four moisture states:

Oven dry: all moisture removed
Air dry: internal pores partially full & surface dry
Saturated-surface dry: pores full & surface moisture removed
Wet: pores full and surface film

SSD aggregate does not add or subtract water
Not easily obtained in the field

Moisture Absorption

We must determine how much water dry aggregate will consume into its voids
This takes water away from the mix and reduces workability & W/C ratio
We adjust mix proportions for absorption
We want to:

provide aggregates water for absorption
maintain workability of the mix

Shape and surface texture of aggregates

The shape of aggregate is an important characteristic since it affects the workability of concrete.It is difficult to measure the shape of irregular shaped aggregates. Not only the type of parent rock but also the type of crusher used also affects the shape of the aggregate produced. Good Granite rocks found near Bangalore will yield cuboidal aggregates. Many rocks contain planes of jointing which is characteristics of its formation and hence tend to yield more flaky aggregates. The shape of the aggregates produced is also dependent on type of crusher and the reduction ratio of the crusher. Quartzite which does not possess cleavage planes tend to produce cubical shape aggregates. From the standpoint of economy in cement requirement for a given water cement ratio rounded aggregates are preferable to angular aggregates. On the other hand, the additional cement required for angular aggregates is offset to some extent by the higher strengths and some times greater durability as a result of greater Interlocking

texture of the hardened concrete. Flat particles in concrete will have objectionable influence on the workability of concrete, cement requirement, strength and durability. In general excessively flaky aggregates make poor concrete. while discussing the shape of the aggregates, the texture of the aggregate also enters the discussion because of its close association with the shape. Generally round aggregates are smooth textured and angular aggregates are rough textured. Therefore some engineers argue against round aggregates from the point of bond strength between aggregates and cement. But the angular aggregates are superior to rounded aggregates from the following two points:
Angular aggregates exhibit a better interlocking effect in concrete, which property makes it superior in concrete used for road and pavements.The total surface area of rough textured angular aggregate is more than smooth rounded aggregates for the given volume. By having greater surface area, the angular aggregates may show higher bond strength than rounded aggregates.The shape of the aggregates becomes all the more important in case of high strength and high performance concrete where very low water/cement ratio is required to be used . In such cases cubical aggregates are required for better workability.

Surface texture is the property, the measure of which depends upon the relative degree to which particle surface are polished or dull, smooth or rough. Surface texture depends upon hardness, grain size, pore structure, structure of the rock and the degree to which the forces acting on it have smoothened the surface or roughened. Experience and laboratory experiments have shown that the adhesion between cement paste and the aggregate is influenced by several complex factors in addition to the physical and mechanical properties. As surface smoothness increases, contact area decreases, hence a highly polished particle will have less bonding area with the matrix than a rough particle of the same volume. A smooth particle , however, will require a thinner layer of paste to lubricate its movements with respect to another aggregate particle. It will therefore permit denser packing because of enhanced workability.

Aggregate:Shape and Surface Texture

Ideal aggregates:

spherical or cubical
round shape, fine porous surface
reduced particle interaction (friction)
results in good workability and good surface area for bonding
natural sands are good examples of this

Non Ideal aggregates:

angular
elongated
flaky or rough
high particle interaction
requires more cement paste to achieve workability
results in increased cost

Rounded: Good workability, low water demand, poor bond
Irregular: Fair workability, low water demand
Angular: Increased water demand, good bond
Elongated : May lack cohesion and require increased fines
Flaky: Aggregate stacks give workability problems

Coarse Aggregate Texture

Glassy.
Smooth.
Granular.
Crystalline
Honeycombed and porous.

- Depends on: rock hardness, grain size, porosity, previous exposure.
- Aggregate shape and texture affect the workability of fresh concrete through their influence on cement paste requirements.
- Sufficient paste is required to coat the aggregates and to provide lubrication to decrease interactions between aggregate particles during mixing.
- Ideal particle is one close to spherical in shape (well rounded and compact) with a relatively smooth surfaces (natural sands and gravels come close to this ideal).
- More angular shapes - rough surfaces – interfere with the movement of adjacent particles (less workable) –They also have a higher surface –to –volume ratio – more paste.
- Flat or elongated aggregates should be avoided.
- Rough surface requires more lubrication for movement (crushed stone).
- Shape can influence strength by increasing surface area available for bonding with the paste.
- Rough surfaces –improve mechanical bond.
- Irregular aggregates (angulars) –higher internal stress concentrations –easier bond failure.

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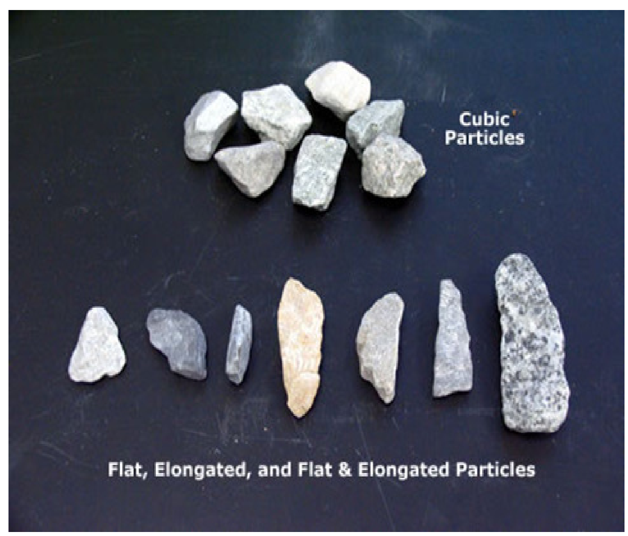
Flaky Aggregates



Aggregate characteristics like Shape, Size and Textues Influence the following

Fresh concrete

- Mix proportions
- Workability / water demand
- Cohesion / pumpability
- Air content / entrainment

Hardened concrete

- Strength
- Density
- Shrinkage
- Skid & abrasion resistance
- Elastic modulus
- Durability
- Color.

For tests on aggregates please refer text books and concrete testing manuals.