Raw Materials for Concrete

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Concrete
Man made stone
Concrete – Proportion Vs Cost

<table>
<thead>
<tr>
<th>VOLUME</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEMENT</td>
<td>70%</td>
</tr>
<tr>
<td>FINE AGGREGATE</td>
<td>10%</td>
</tr>
<tr>
<td>COARSE AGGREGATE</td>
<td>20%</td>
</tr>
</tbody>
</table>

10%  
15%  
25%  
59%
Concrete Properties

- Versatile
- Pliable when mixed
- Strong & Durable
- Does not Rust or Rot
- Does Not Need a Coating
- Resists Fire
Concrete Constituents

- Mixture of aggregate and paste
- Paste 30 to 40%
  - Portland cement (by Vol.) 7% to 15%
  - Water 14% to 21% by Vol.
- Aggregates 60% to 70% by vol.
  - Coarse aggregates
  - Fine aggregates
- Admixtures
Ordinary Portland Cement

- Dry powder (grey) of very fine particles
- Forms a paste when mixed with water
- Chemical reaction-Hydration
- Glue (Binder)
- Paste coats all the aggregates together
- Hardens and forms a solid mass
These compounds present in the raw materials when subjected to high clinkering temperature combine with each other to form compounds called Bogue’s compound -

- **Tricalcium silicate** $3 \text{CaO}.\text{SiO}_2$  \hspace{1cm} C$_3$S
- **Dicalcium silicate** $2 \text{CaO}.\text{SiO}_2$  \hspace{1cm} C$_2$S
- **Tricalcium Aluminate** $3 \text{CaO}.\text{Al}_2\text{O}_3$  \hspace{1cm} C$_3$A
- **Tretracalcium Aluminoferrite** $4 \text{CaO}.\text{Al}_2\text{O}_3.\text{Fe}_2\text{O}_3$  \hspace{1cm} C$_4$AF
Compounds Composition

✓ Compound composition using Bogue’s Equation (In Percent)

<table>
<thead>
<tr>
<th>Compound</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃S</td>
<td>54.1</td>
</tr>
<tr>
<td>C₂S</td>
<td>16.6</td>
</tr>
<tr>
<td>C₃A</td>
<td>10.8</td>
</tr>
<tr>
<td>C₄AF</td>
<td>9.1</td>
</tr>
</tbody>
</table>
✓ Tricalcium silicate & dicalcium silicate constitute 70 to 80% of cement & are the most important compounds responsible for strength.

✓ Also modifications in cement can be made which will lead to the production of different types of cement as will be discussed separately in further course of the discussion.
Rate of heat of hydration of pure compounds

Time (log scale) - days

Fraction Hydrated

- C3S
- C2S
- C3A
- C4AF

ACC Concrete Ltd.
Raw materials for concrete

Date: 2011
CALCIUM SILICATE HYDRATES:

- During the course of reaction of C\textsubscript{3}S and C\textsubscript{2}S with water, Calcium silicate hydrates (C-S-H) and Ca(OH)\textsubscript{2} are formed.

\[2 \text{C}_3\text{S} + 6\text{H} \rightarrow \text{C}_3\text{S}_2\text{H}_3 + 3\text{Ca(OH)}_2\]

\[2 \text{C}_2\text{S} + 4\text{H} \rightarrow \text{C}_3\text{S}_2\text{H}_3 + \text{Ca(OH)}_2\]
Types of Cement

1) Ordinary Portland Cement
   a) O.P.C 43 Grade - IS:8112:1989
   b) O.P.C 53 Grade - IS:12269:1987

2) Rapid Hardening Cement - IS:8041:1990

3) Sulphate Resisting Cement - IS:12330:1988


6) Portland Pozzolana Cement - IS:1489 (Part I)
Type III - High Early

Type I - Normal

Type IV - Low Heat of Hydration
Water

- Needed for two purposes:
  - chemical reaction with cement
  - workability
- Only 1/3 of the water is needed for chemical reaction
- Extra water remains in pores and holes
- Results in porosity
- **Good** for preventing plastic shrinkage cracking and workability
- **Bad** for permeability, strength, durability.
Water

- Permissible Limits for Solids as per Table 1 IS:456-2000

<table>
<thead>
<tr>
<th>Material</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic</td>
<td>200 mg/ml</td>
</tr>
<tr>
<td>Inorganic</td>
<td>3000 mg/ml</td>
</tr>
<tr>
<td>Sulphates (as SO$_3$)</td>
<td>400 mg/ml</td>
</tr>
<tr>
<td>Chlorides (as Cl)</td>
<td>2000 mg/ml</td>
</tr>
<tr>
<td>Suspended matter</td>
<td>2000 mg/ml</td>
</tr>
</tbody>
</table>
Aggregates

- Cheap fillers
- Hard material
- Provide for volume stability
- Reduce volume changes
- Provide abrasion resistance
Aggregates

1) **Introduction**

- Aggregates are important constituents in concrete & give body to the concrete
- Reduce shrinkage & Effect economy
- Occupy 70-80% of volume of concrete

2) **Classification**

- Aggregates can be classified as:
  - Normal weight aggregates
  - Heavy weight aggregates
Aggregates

• **Fine aggregates:**
  
  ✓ Natural or manufactured sand with particles up to 10mm. Generally, sand particles almost entirely pass the 4.75 mm sieve and are predominantly retained on the 75µm sieve.

• **Coarse aggregates:**
  
  ✓ Natural gravel or manufactured material. The particles are predominantly retained on the 4.75 mm sieve.
Aggregates

- **Size of Aggregates:**

  - MAS that can be used are governed by the following factors:
    - Thickness of section (not larger than 1/5\(^{th}\))
    - Spacing of reinforcement (not larger than 3/4\(^{th}\) of clear distance)
    - Clear Cover
    - Mixing, Handling, & placing techniques.
    - MAS of 20mm is widely used for Structural & Road Works.
    - MAS of 10mm is used in shotcrete.
    - MAS of 80 to 150mm is used for mass concreting.
Aggregates

- **Shape of Aggregates:**
  - The shape of aggregates is an imp. characteristic since it affects the workability of concrete.
  - Flaky particles have influence on workability, cement requirement, interlocking, strength, & durability.
  - The grading, the shape and the texture of aggregates can significantly influence concrete workability.
Aggregates

The amount of water required for a target workability is related to aggregate properties:

- Nominal maximum size of the coarse aggregate.
- Shape and texture of particles of fine and coarse aggregates.
- Grading of coarse aggregate.
Aggregates

- Angular sand (manufactured sand) can significantly increase the water demand and the cement content for a required slump.

- Very coarse sands and coarse aggregates can produce harsh, unworkable mixes.

- Changes in grading (or the shape / texture) of the aggregates can cause changes in the water demand of concrete, segregation and affect uniformity of concrete from batch to batch.
Aggregates

Effect of aggregate size on cement requirement (constant w/c & slump)
# Types of aggregates for concrete

<table>
<thead>
<tr>
<th>Weight categories</th>
<th>Uses</th>
<th>Indicative concrete density (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra lightweight density &lt; 500 kg/m$^3$</td>
<td>Thermal insulation</td>
<td>500 to 1000</td>
</tr>
<tr>
<td>Lightweight density &lt; 2100 kg/m$^3$</td>
<td>Lightweight structural concretes</td>
<td>100 to 1800</td>
</tr>
<tr>
<td>Normal-weight density &gt; 2100 kg/m$^3$</td>
<td>Normal-weight structural concretes</td>
<td>2000 to 2600</td>
</tr>
<tr>
<td>Heavyweight density &gt; 3200 kg/m$^3$</td>
<td>Heavyweight concrete Radiation-shielding</td>
<td>3000 to 5000</td>
</tr>
</tbody>
</table>
Properties of fine aggregates:

<table>
<thead>
<tr>
<th>Properties</th>
<th>Road Works</th>
<th>Structural Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Fineness Modulus</td>
<td>-</td>
<td>2.0 to 3.5</td>
</tr>
<tr>
<td>2) Water Absorption</td>
<td>Max. 2%</td>
<td>Max. 2%</td>
</tr>
<tr>
<td>3) Soundness Test:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Sodium Sulphate</td>
<td>Max. 10%</td>
<td>Max. 10%</td>
</tr>
<tr>
<td>b) Magnesium Sulphate</td>
<td>Max. 15%</td>
<td>Max. 15%</td>
</tr>
</tbody>
</table>
Aggregates

• Grading of Coarse Aggregates as per Table 2 of IS:383-1970

<table>
<thead>
<tr>
<th>I.S Sieve (mm)</th>
<th>63mm</th>
<th>40mm</th>
<th>20mm</th>
<th>16mm</th>
<th>12.5mm</th>
<th>10mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>63</td>
<td>85 - 00</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>40</td>
<td>0 - 30</td>
<td>85-100</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>0 to 5</td>
<td>0-20</td>
<td>85-100</td>
<td>100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>85-100</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>12.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>85 to 100</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>0 to 5</td>
<td>0 to 5</td>
<td>0 to 20</td>
<td>0 to 30</td>
<td>0 to 45</td>
<td>85 to 100</td>
</tr>
<tr>
<td>4.75</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0 to 5</td>
<td>0 to 5</td>
<td>0 to 10</td>
</tr>
<tr>
<td>2.36</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0 to 5</td>
</tr>
</tbody>
</table>
### Grading of Fine Aggregates as per Table 4 IS:383-1970:

<table>
<thead>
<tr>
<th>I.S Sieve (mm)</th>
<th>% Passing</th>
<th>River Sand</th>
<th>Crushed Sand (Manufactured Sand)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zone I</td>
<td>Zone II</td>
<td>Zone III</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>4.75</td>
<td>90-100</td>
<td>90-100</td>
<td>90-100</td>
</tr>
<tr>
<td>2.36</td>
<td>60-95</td>
<td>75-100</td>
<td>85-100</td>
</tr>
<tr>
<td>1.18</td>
<td>30-70</td>
<td>55-90</td>
<td>75-100</td>
</tr>
<tr>
<td>0.6</td>
<td>15-34</td>
<td>35-59</td>
<td>60-79</td>
</tr>
<tr>
<td>0.3</td>
<td>5-20</td>
<td>8-30</td>
<td>12-40</td>
</tr>
<tr>
<td>0.15</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
</tr>
</tbody>
</table>

The Permissible Limit on 150 micron Sieve is increased to 20 Percent (all other limits remaining same)
Aggregates

- Once the individual grading of coarse & fine aggregates are fixed then they are combined to get the most suitable grading.

- The process of combining aggregates is a trial & error method.

- A sample calculation for this is shown.
Reduction of Voids

25 mm

9 mm
Reduction of Voids

Figure 7-6 Reduction in the volume of voids on mixing fine and coarse aggregates.
## Combined Aggregate Gradation

<table>
<thead>
<tr>
<th>Seive Size (mm)</th>
<th>Individual Grading</th>
<th>Combined Grading</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 mm</td>
<td>10 mm</td>
<td>C. Sand</td>
</tr>
<tr>
<td>20</td>
<td>95.5</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>0.1</td>
<td>88.7</td>
<td>100</td>
</tr>
<tr>
<td>4.75</td>
<td>0</td>
<td>9.2</td>
<td>98.6</td>
</tr>
<tr>
<td>2.36</td>
<td>0</td>
<td>1.1</td>
<td>84.6</td>
</tr>
<tr>
<td>1.18</td>
<td>0</td>
<td>0</td>
<td>52.1</td>
</tr>
<tr>
<td>0.6</td>
<td>0</td>
<td>0</td>
<td>39.5</td>
</tr>
<tr>
<td>0.3</td>
<td>0</td>
<td>0</td>
<td>30.1</td>
</tr>
<tr>
<td>0.15</td>
<td>0</td>
<td>0</td>
<td>21.8</td>
</tr>
</tbody>
</table>
### Moisture conditions of Aggregates

<table>
<thead>
<tr>
<th>State</th>
<th>Oven dry</th>
<th>Air dry</th>
<th>Saturated, surface dry</th>
<th>Damp or wet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Moisture</strong></td>
<td>None</td>
<td>Less than potential absorption</td>
<td>Equal to potential absorption</td>
<td>Greater than absorption</td>
</tr>
</tbody>
</table>

![Images of aggregate states](images)
Bulking of Sands

Percent increase in volume over dry, rodded, sand

Percent of moisture added by mass to dry, rodded sand

- Fine sands
- Medium sands
- Coarse sands
Background Data

- Sieve analysis of fine & coarse aggregates: fineness modulus
- Dry-rodded unit weight of coarse aggregate
- Bulk specific gravity of materials
- Absorption capacity, or free moisture in the aggregate
- Variations in the approximate mixing water requirement with slump, air content, and grading of the available aggregates
- Relationships between strength & w/c ratio for available combinations of cement & aggregate
- Job specifications if any
# Combined Gradation for Pump Concrete as per ACI 304.2R-91:

<table>
<thead>
<tr>
<th>IS Sieve (mm)</th>
<th>% Passing</th>
<th>25mm Max. Size</th>
<th>20mm Max. Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>80-88</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>13</td>
<td>64-75</td>
<td></td>
<td>75-82</td>
</tr>
<tr>
<td>9.5</td>
<td>55-70</td>
<td></td>
<td>61-72</td>
</tr>
<tr>
<td>4.75</td>
<td>40-58</td>
<td></td>
<td>40-58</td>
</tr>
<tr>
<td>2.36</td>
<td>28-47</td>
<td></td>
<td>28-47</td>
</tr>
<tr>
<td>1.18</td>
<td>18-35</td>
<td></td>
<td>18-35</td>
</tr>
<tr>
<td>0.6</td>
<td>12-25</td>
<td></td>
<td>12-25</td>
</tr>
<tr>
<td>0.3</td>
<td>7-14</td>
<td></td>
<td>7-14</td>
</tr>
<tr>
<td>0.15</td>
<td>3-8</td>
<td></td>
<td>3-8</td>
</tr>
<tr>
<td>0.075</td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
Admixtures

- Admixture can be defined as a chemical product which is added to the concrete batch immediately before or during mixing or during an additional mixing operation prior to the placing of concrete for the purpose of achieving specific modifications to the normal properties of concrete.

- Admixtures are commonly classified by their function in concrete but often they exhibit some additional action.
Why do we need Admixtures:

- Concrete must be placeable and durable.
- High degree of workability is required in case of thin walls, tremie concreting, pumping of concrete.
- Durability includes limitation for water to cement ratio so that the concrete structure maintains its required strength and serviceability.
Admixtures

- Admixtures are generally used to achieve the following:

**In Fresh Concrete:**

- Increase workability and/or pumpability without increasing the w/c ratio.
- Improve cohesiveness and thereby reducing segregation or bleeding.
- Improve to some extent set retardation
- Entrain air bubbles in the fresh concrete.
Admixtures

In Hardened Concrete:

- Increase strength by reducing w/c ratio, maintaining the same workability
- Reduce permeability and improve durability by reducing w/c ratio.
- Reduce heat of hydration & drying shrinkage by reducing cement content.
The classification of ASTM C 494-92 is as follows:

- **Type A** - Water reducing
- **Type B** - Retarding
- **Type C** - Accelerating
- **Type D** - Water reducing and retarding
- **Type E** - Water reducing and accelerating
- **Type F** - High range water reducing (HRWRA)
- **Type G** - High range water reducing & Retarding
Classification of superplasticizer:

- Sulphonated napthalene-formaldehyde condensates (SNF)
- Sulphonated melamine-formaldehyde condensates (SMF).

Fourth generation Superplasticizers:

- Polycarboxylate Ether (PCE)
- Acrylic polymer based (AC)
- Multicarboxylate Ether
How they work

Cement particles in the absence of a dispersing admixture

Surface of cement grains not available for hydration

Entrapped water

Cement particles / grains
How they work

Cement particles in the presence of a dispersing admixture

Individual cement particles / grains
Compatibility Issues

- Laboratory tests shall be carried out to establish compatibility of cement-plasticizer/superplasticizer system to determine the optimum dosage of admixture, initial slump, extent of slump retention with time and compressive strengths at various ages as percent of control sample etc.

- Any adverse affects between cement and chemical admixtures such as rapid set or abnormal slump loss, excessive retardation, increased air content, bleeding etc, has been often referred to as the “cement-admixture incompatibility”.
“Cold” Joint

First lift hardened prior to the placement of the 2nd lift
Mineral Admixtures (MA)
MA: Key components for durable concrete

- The latest developments in concrete technology are attributable to the use of superplasticizers and mineral components.
Introduction

- Also called ‘Supplementary Cementing Materials’

- Used when special performance is needed: Increase in strength, reduction in water demand, impermeability, low heat of hydration, improved durability, correcting deficiencies in aggregate gradation (as fillers), etc.

- Result in cost and energy savings: Replacement of cement leads to cost savings; energy required to process these materials is also much lower than cement

- Environmental damage and pollution is minimized by the use of these by-products

- Usage depends on supply and demand forces, as well as the market potential and attitudes
### Typical compositions

<table>
<thead>
<tr>
<th>% by mass</th>
<th>PC</th>
<th>GGBFS</th>
<th>F-FA</th>
<th>C-FA</th>
<th>SF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SiO₂</strong></td>
<td>21</td>
<td>35</td>
<td>50</td>
<td>35</td>
<td>90</td>
</tr>
<tr>
<td><strong>Al₂O₃</strong></td>
<td>5</td>
<td>8</td>
<td>25</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td><strong>Fe₂O₃</strong></td>
<td>2</td>
<td>3</td>
<td>10</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td><strong>CaO</strong></td>
<td>65</td>
<td>40</td>
<td>1</td>
<td>20</td>
<td>-</td>
</tr>
</tbody>
</table>

PC: Portland cement, GGBFS: Ground granulated blast furnace slag, F-FA: Type F fly ash, C-FA: Type C fly ash, SF: Silica fume
RILEM Classification

- Cementitious
- Highly pozzolanic: Silica fume, Rice husk ash (controlled burning)
- Normally pozzolanic: Class F fly ash
- Cementitious and pozzolanic: GGBFS, Class C fly ash
- An additional category is also suggested by researchers – Weak pozzolans, such as slowly cooled and ground slag, bottom ash, and field-burnt rice husk ash
Pozzolans

- Pozzolans are siliceous or aluminous materials, which possess by themselves little or no cementitious properties, but in finely divided form react with calcium hydroxide in the presence of moisture at ordinary temperatures to form compounds possessing cementitious properties (definition according to ASTM C595).
Pozzolanic reaction

- CH + Reactive SiO$_2$ (or Al$_2$O$_3$) + H$_2$O $\rightarrow$ C-S-H (or C-A-H)

- Reaction is
  - Lime consuming
  - Pore refining
  - Interface refining (why?)
  - Slow (low heat of hydration)
  - Accelerated by alkalis and gypsum
Pozzolanic reaction

OPC/silicates + Water → Hydration reaction → C-S-H

Ca(OH)₂ or Portlandite + Pozzolanic reaction → C-S-H + Fly ash
Pozzolanic reaction

t_{eff} values for:
- Rice husk ash: 1 day
- Silica fume: 1 – 2 days
- Type C fly ash: 3 – 7 days
- Type F fly ash: 14 – 28 days
- GGBFS: 3 – 7 days

Age

PC/Poz

PC

$ t_{eff} $
Pozzolanic activity

- Pozzolanic activity is evaluated using the Pozzolanic Activity Index test, which defines the index as:

  \[ \text{PAI} \, (\%) = \frac{\text{Strength} \, (\text{PC/pozzolan mixture}) \times 100}{\text{Strength} \, (\text{PC mixture})} \]

- In this test, the mix design is done using a volumetric replacement of cement by the pozzolan (ASTM C311) as opposed to the Slag Activity Index test (ASTM C989) where a mass replacement is used.
Fly Ash

Source

- By-product obtained during combustion of coal in thermal power plants
- The quality and composition of fly ash depends on the type of coal being burnt
Need for fly ash utilization

- Nearly 73% of India’s total power generation is thermal (mostly using coal)
- 100 million tons of fly ash being generated annually
- World Bank - by 2015, disposal of coal ash would require 1000 square kilometres or one square metre of land per person in India
Collection of fly ash

- During combustion of coal, 75 – 80% of the ash flies out with the flue gas, and is thus called ‘fly ash’. The ash that doesn’t fly out is called ‘bottom ash’. This can be processed as aggregate, but is generally not used in concrete.

- The collection of fly ash is done using the following two types of precipitators:
  - Bag-house precipitator
  - Electrostatic precipitator

- The bag-house precipitator is found to be more efficient, and removes out very fine material
P.J. Tikalsky, "The effect of Fly ash on the Surface Resistance of Concrete"
Six ESP fields in series

Gas inlet

Gas outlet

Mixed ash from all fields

Fieldwise Graded Ash

4 Rows
<table>
<thead>
<tr>
<th>Field No.</th>
<th>NTPC Ramagundam</th>
<th>NTPC Dadri</th>
<th>PSEB Bhatinda</th>
<th>MSEB Parli</th>
<th>NTPC Unchahar</th>
<th>Raichur TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>337</td>
<td>333</td>
<td>324</td>
<td>224</td>
<td>273</td>
<td>255</td>
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<td>5</td>
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<td>407</td>
<td>652</td>
<td>484</td>
<td>-</td>
<td>360</td>
</tr>
<tr>
<td>6</td>
<td>678</td>
<td>439</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>600</td>
</tr>
</tbody>
</table>
ASTM Classification

- **Type C**: This is also called High Calcium (CaO) fly ash, and possesses both cementitious and pozzolanic properties. 10 – 15% of the material has a particle size greater than 45 μm, and the fineness (Blaine) is 300 – 400 m\(^2\)/kg. The particles are primarily solid spheres with a smooth texture. The average particle size is less than 20 μm.

- **Type F**: This is also called Low Calcium (CaO) fly ash, and is a normally pozzolanic material. 15 – 20% of the material is larger than 45 μm, and the fineness is 200 – 300 m\(^2\)/kg. Particles are solid spheres with a smooth texture, and the average particle size is 20 μm.
Apart from solid spherical particles, there also may exist hollow spheres. The small hollow spheres with entrapped gas are called cenospheres, while the large hollow spheres with solid spheres inside them are called plerospheres.

wwwctlgroupcomgroupcontentasp?
Effects on fresh concrete

- The setting time is increased when fly ash is used.
- Workability and flow of concrete are increased due to the spherical shape of the fly ash particles, which lends a ball-bearing type effect on the concrete mixture.
- Bleeding and segregation are usually reduced for well-proportioned fly ash concrete.
- The paste volume is increased when mass replacement of cement by fly ash is done.
Effects on hardened concrete

- Strength gain of fly ash concrete is slower than normal concrete, as stated in the previous sections. Ultimate strengths are usually improved when fly ash is used.

- Creep and shrinkage of fly ash concrete are typically higher than normal concrete, because of the increased amount of paste in the concrete (when mass replacement is done).

- More air-entraining admixture is needed to entrain air in fly-ash concrete.

- The results on the effects of fly ash on sulphate resistance are inconclusive.

- Expansions during alkali aggregate reaction are reduced by the use of fly ash, because of the dilution of Portland cement (implying there are lesser alkalis available).
Specialized applications

- In high strength concrete, as an additional cementitious material.
- In roller-compacted concrete. Fly ash is good for bonding in-between the layers of this concrete.
- In controlled low-strength materials (CLSM), which are flowable mortars used as backfill.
- As a synthetic aggregate.
- For manufacture of bricks.
ACC Concrete Ltd.

Raw materials for concrete

Date: 2011
Problems with fly ash

 Due to transportation cost, the use of fly ash beyond 40-50 km from the thermal power plant becomes uneconomical

 Lack of appropriate technologies for handling and transportation

 Lot of scope for development of this technology in India
Silica fume Or Microsilica
By-product of ferrosilicon industry

Purity of silica fume depends on the ferrosilicon alloy from which Si metal is being extracted

<table>
<thead>
<tr>
<th>Ferrosilicon alloys</th>
<th>SiO₂ content</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeCrSi</td>
<td>18 – 48%</td>
</tr>
<tr>
<td>FeMgSi</td>
<td>44 – 48%</td>
</tr>
<tr>
<td>50% ferrosilicon</td>
<td>72 – 77%</td>
</tr>
<tr>
<td>70% ferrosilicon</td>
<td>84 – 88%</td>
</tr>
<tr>
<td>Silicon metal (98%)</td>
<td>93 – 98%</td>
</tr>
</tbody>
</table>
Other variants

- Silica flour, fume silica (a white fluffy material produced from vapour phase hydrolysis of chlorosilanes such as SiCl$_4$ in the flame of hydrogen and oxygen, used in the paint industry as filler), silica gel, and precipitated silica.
## Comparison of Chemical and Physical Characteristics - Silica Fume, Fly Ash and Cement

<table>
<thead>
<tr>
<th></th>
<th>Silica Fume</th>
<th>Fly Ash</th>
<th>Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SiO₂ Content</strong></td>
<td>85- 97</td>
<td>35 - 48</td>
<td>20 -25</td>
</tr>
<tr>
<td><strong>Surface Area m²/kg</strong></td>
<td>17,000 - 30,000</td>
<td>400 - 700</td>
<td>300 - 500</td>
</tr>
<tr>
<td><strong>Pozzolanic Activity</strong></td>
<td>120 - 210</td>
<td>85 - 110</td>
<td>n/a</td>
</tr>
<tr>
<td>(with cement, %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pozzolanic Activity</strong></td>
<td>1,200 - 1,660</td>
<td>800 - 1,000</td>
<td>n/a</td>
</tr>
<tr>
<td>(with lime, psi) (MPa)</td>
<td>(8.3 - 11.4)</td>
<td>(5.5 - 6.9)</td>
<td></td>
</tr>
</tbody>
</table>
Silica fume available as:

- As is bulk powder: Due to the low specific gravity of silica fume (~2.2), the bulk powder becomes very bulky and difficult to handle and transport.

- Dry-densified silica fume: Compaction by pressure is used to flocculate the silica fume particles. An efficient superplasticizer is required to deflocculate and cause a good dispersion of the silica fume in concrete.

- Slurry: 50% water + 47% silica fume + 3% chemical agent, that keeps the particles in suspension and prevents gelling. The slurry form is susceptible to gelling in cold climates. However, it is a very efficient way of dispensing silica fume. Also, storage space can also be reduced.
Properties

- Specific gravity: 2.2
- Typical fineness: 20000 $m^2/kg$
- Colour: light grey to dark grey (lighter implies purer)
- Cost: almost 10 times as much as PC
- Typically used at 5 – 15% replacement level
- Benefits from silica fume are due to the pozzolanic reaction that produces additional C-S-H, as well as due to the particle packing (filler effect) of the fine silica fume particles
Effects on fresh concrete

- Because of its high fineness, the use of silica fume causes an increase in the water demand of concrete. Typically it is always used in conjunction with a superplasticizer.

- Silica fume causes the mix to be sticky and cohesive. Also, concrete mixes with silica fume are prone to slump loss problems. Because of its cohesiveness, a higher slump is needed to place silica fume concrete.

- Bleeding is reduced drastically. In fact, most silica fume mixes do not show any bleeding. In dry areas, if the evaporation rate exceeds the rate at which concrete sets, plastic shrinkage may occur.
Plastic shrinkage problems

\[ P_c (\text{capillary tension}) = 0.001\gamma S/(w/c), \]

where \( \gamma = \text{surface tension of water} = 0.0073 \text{ N/m} \), and \( S = \text{surface area of particles} \) (20000 m\(^2\)/kg for SF, 350 m\(^2\)/kg for cement).

Assuming a w/c of 0.35,

For PC concrete, \( P_c = 0.07 \text{ MPa} \)
For SF concrete, \( P_c = 4.20 \text{ MPa} \)

M. D. Cohen, unpublished
Effects on hardened concrete

- Pore size refinement and reduction in permeability occurs when silica fume is used.
- Compressive and flexural strengths are increased.
- Elastic modulus is increased ($E_{SFC} \sim 150\% E_{PCC}$), or, in other words, concrete becomes stiffer with the use of silica fume.

D.W. Christen, E.V. Sorenson & F.F. Radjy, "Rockbond: A New Microsilica Concrete Bridge Deck Overlay Material"
Creep and shrinkage are increased at high replacement levels (10 – 15%) because of an increase in the volume of the paste.

Amount of air-entraining agent required for a particular volume of air is increased in silica fume concrete. Freeze-thaw resistance is reduced slightly compared to normal concrete, but damage is usually limited owing to the extremely low permeability of SFC.

In most cases, silica fume concrete shows better resistance to chemical attack (exceptions being ammonium sulphate and magnesium sulphate attack), owing to the decreased permeability, as well as due to reduced CH in the paste.

Expansions due to ASR are reduced in silica fume concrete.
Corrosion rate is reduced with the use of silica fume. This is because of two reasons: the low permeability of SFC causes a lower availability of moisture and oxygen at the cathodic sites, and the high resistivity of SFC makes the flow of electrons difficult.

- Carbonation depth is generally lowered.
- SFC has very good abrasion and erosion resistance.
- Fire performance of SFC is not very good.
Applications of Silica fume concrete

- Ultra High Strength Requirements
- High Abrasion Resistance
- Early-Age Strength Improvement
- Corrosion Protection
- Repair Applications
Ground-granulated blast furnace slag (GGBFS)

Actually, slag should not be classified as an admixture; it is a hydraulic cement!!
Blast furnace slag is a by-product of the extraction of iron from iron ore. Coke and limestone are added as fluxes inside the blast furnace. The impurities in iron ore combine with the lime and rise up to the surface of the blast furnace, while the molten iron, which is heavier, stays at the bottom.

1892 was the first time that Portland-blast furnace slag cement was manufactured. In the present day scenario, slag is used almost in every country to varying degrees.

The reactivity of slag depends on the rate of cooling. In increasing order of reactivity, the cooling processes may be ranked as: Slow cooling (in air), Rapid cooling (by water spray), and Quenching (dipping in water).

M. Regourd, "Slags and Slag Cements"
Types of slag

- Air cooled slag: Low reactivity slag that finds use as aggregate. The strength and toughness of this aggregate makes it a very suitable material for railroad ballast.

- Expanded or foamed slag: Low reactivity slag that is foamed with air. Makes a very good lightweight aggregate, and is used for thermal insulation.

- Granulated: This is a high reactivity slag, and is usually quenched. The hardened matter is then ground to a fineness similar to cement. Thus the name: Ground Granulated Blast Furnace Slag (GGBFS).

- Pelletized slag: The reactivity is similar to GGBFS, but the process of pelletization is a complex one. Typically, this type of slag is not used as much as GGBFS.
Factors governing properties

- Chemical composition of GGBFS
- Alkali concentration of reacting system
- Glass (reactive SiO$_2$) content of GGBFS
- Fineness of GGBFS and PC
- Temperature during early phase of hydration
Hydration of slag

- An activator is necessary to hydrate the slag. The activation of slag hydration can be done in the following ways:
  - Alkali activation: e.g. by caustic soda (NaOH), Na$_2$CO$_3$, sodium silicate, etc. The products formed are C-S-H, C$_4$AH$_{13}$ and C$_2$ASH$_8$ (Gehlenite).
  - Sulphate activation: e.g. by gypsum, hemihydrate, anhydrite, phosphogypsum, etc. The products formed are C-S-H, ettringite, and aluminium hydroxide (AH$_3$).
  - Mixed activation: When both alkali and sulphate sources are present, such as in a cement system.
Effects on concrete properties

- Apart from delaying the initial set and strength gain, slag does not significantly alter the fresh concrete properties.
- The ultimate strengths with slag are generally improved; the durability is also improved with the replacement of cement by slag.
Other mineral admixtures
Rice husk ash

- This is a high reactivity pozzolan obtained by controlled calcination of rice husk.

- Field-burnt rice husk is almost crystalline in nature, and makes a weak pozzolan. Thus, to obtain a high degree of pozzolanicity, a good control is needed while burning.

- RHA usually contains a large amount of unburnt carbon which might adversely affect air entrainment.

- RHA is a fine material, with particle sizes less than 45 μm, and a surface area of 60000 m²/kg.

- The particles are typically cellular. A high amount of reactive silica is present in the system (> 90%).
### Metakaolin

- This is obtained from calcination of kaolinite clay in the range of 740 – 840 °C. The crystalline clay loses its structure at this temperature by the loss of bound water. Burning should strictly be done in this range, since beyond 1000 °C, recrystallization of the clay occurs.

- A general formula of metakaolin can be written as \( \text{AS}_2 \). This compound reacts with CH to form additional C-S-H.

- The content of C-S-H and its formation rate depends on the mineralogical characteristics of the kaolin precursor.

- Metakaolin has a performance comparable to silica fume as a mineral admixture in concrete.

- Since MK is not a by-product, its processing is an expensive affair. Thus the marketability of MK is not as good as silica fume, which is a proven by-product.
MK reaction

The aluminosilicate compound $\text{AS}_2$ reacts with CH produced during cement hydration in the following form (suggested by Murat – in Cement and Concrete Research, Vol. 13, 1983):

$$\text{AS}_2 + 6\text{CH} + 9\text{H} \rightarrow \text{C}_4\text{AH}_{13} + 2\text{C-S-H}$$

C-S-H formed in this reaction is aluminous, with a C/S ranging from 0.83 (for crystalline forms of C-S-H) to $>1.5$ (for amorphous and semi-crystalline forms of C-S-H).
SILICA FUME

CEMENT

FLY ASH

VOLUME %

0.52

0.44

0.34

Raw materials for concrete