Chapter 3: Aggregates for Concrete

Introduction

Aggregates form the bulk of concrete volume—nearly 60–75%—and hence significantly influence the properties of both fresh and hardened concrete. They not only provide dimensional stability and durability but also contribute to the economy of concrete. The selection, grading, shape, and texture of aggregates directly impact workability, strength, and long-term performance. Therefore, understanding the classification, properties, testing methods, and role of aggregates is crucial in Concrete Technology.

3.1 Classification of Aggregates

Aggregates are broadly classified based on size, origin, shape, and specific gravity.

3.1.1 Based on Size

1. **Fine Aggregates**:
   - Size: Less than 4.75 mm
   - Examples: Natural sand, crushed stone sand, crushed gravel sand
   - Passes through 4.75 mm IS sieve and is retained on 75 µm sieve
   - Used to fill voids between coarse aggregates
2. **Coarse Aggregates**:
   - Size: Greater than 4.75 mm
   - Common sizes: 10 mm, 20 mm, 40 mm
   - Examples: Crushed stone, gravel, boulders
   - Provide compressive strength and dimensional stability
3. **All-in Aggregates**:
   - Mixture of both fine and coarse aggregates
   - Used where grading is not very strict

3.1.2 Based on Origin

1. **Natural Aggregates**:

- Obtained from natural sources like river beds, pits, and quarries
- Examples: River gravel, natural sand

2. **Artificial Aggregates**:
   - By-products or manufactured materials
   - Examples: Crushed bricks, blast furnace slag, sintered fly ash
3. **Recycled Aggregates**:
   - Sourced from demolished concrete structures
   - Promotes sustainability in construction

3.1.3 Based on Shape

1. **Rounded Aggregates**:
   - Natural river gravels
   - Low surface area, high workability, lower bond strength
2. **Angular Aggregates**:
   - Crushed rock
   - High surface area and interlock; better strength and less workability
3. **Flaky Aggregates**:
   - Thickness is less than 0.6 times the mean dimension
   - Reduce workability and strength
4. **Elongated Aggregates**:
   - Length is more than 1.8 times the mean dimension
   - Similar effects as flaky particles
5. **Flaky and Elongated Aggregates**:
   - Not preferred in high-strength concrete

3.1.4 Based on Unit Weight

1. **Normal Weight Aggregates**
   - Density: 1520 – 1680 kg/m^3
   - Examples: Crushed stone, gravel
2. **Lightweight Aggregates**
   - Density: < 1120 kg/m^3
   - Used for insulation or structural lightweight concrete

- Examples: Pumice, expanded shale, vermiculite

3. **Heavyweight Aggregates**
   - Density: > 2100 kg/m^3
   - Used in radiation shielding concrete
   - Examples: Barytes, hematite, magnetite

3.2 Properties of Aggregates

The performance of aggregates in concrete depends on several physical and chemical properties.

3.2.1 Physical Properties

- **Size and Grading**: Proper grading ensures minimum voids and optimal paste requirement.
- **Shape and Texture**: Affects workability and strength.
- **Specific Gravity**: Indicates density of aggregates.
- **Bulk Density**: Indicates how aggregates will behave in the concrete mix.
- **Porosity and Absorption**: High porosity increases water absorption and affects water-cement ratio.
- **Moisture Content**: Impacts effective water-cement ratio.

3.2.2 Mechanical Properties

- **Crushing Value**: Measures resistance to crushing under compressive load.
- **Impact Value**: Indicates toughness or resistance to sudden impact.
- **Abrasion Value**: Indicates wear resistance, important for road surfaces.
- **Flakiness and Elongation Index**: Shape indices that affect strength and compaction.

3.2.3 Thermal Properties

- **Thermal Expansion**: Important for fire resistance and thermal stability.
- **Conductivity**: Affects thermal insulation of concrete.

3.3 Grading of Aggregates

Proper grading reduces voids and enhances strength, durability, and workability.

3.3.1 Grading Zones (As per IS: 383)

Fine aggregates are classified into 4 zones:

- **Zone I**: Coarsest
- **Zone II**: Medium
- **Zone III**: Moderately fine
- **Zone IV**: Finest

Note: Zone II sand is preferred for most concrete works.

3.3.2 Gap Grading vs Continuous Grading

- **Continuous Grading**: All particle sizes present, results in dense packing.
- **Gap Grading**: One or more sizes missing, used in architectural finishes.

3.3.3 Fineness Modulus (FM)

- Empirical figure to describe aggregate coarseness
- FM = Cumulative % retained on standard sieves / 100
- Typical FM:
  - Sand: 2.3–3.1
  - Coarse Aggregate: 6–7

3.4 Methods of Combining Aggregates

For optimum mix design, aggregates are often blended from multiple sources or sizes.

3.4.1 Trial and Error Method

Gradation curve of different size fractions plotted and combined proportionately to match desired grading.

3.4.2 Mathematical Method (Graphical/Analytical)

- **Fuller's Formula**:

$$P=\left(\frac{d}{D}\right)^{n}\times 100$$

where:

- P = % passing through sieve size d
- D = maximum aggregate size
- $n \approx 0.5$ for optimum packing

3.5 Testing of Aggregates

Aggregates must be tested to ensure quality and compliance with standards.

3.5.1 Sieve Analysis (IS: 2386 Part I)

- Determines particle size distribution
- Helps in computing Fineness Modulus

3.5.2 Specific Gravity and Water Absorption (IS: 2386 Part III)

- Helps in concrete mix design
- Specific Gravity Types:
  - Apparent Specific Gravity
  - Bulk Specific Gravity (oven-dry and SSD basis)

3.5.3 Aggregate Crushing Value (IS: 2386 Part IV)

- Measures resistance to crushing under compression
- Limit: < 30% for concrete used in roads, < 45% otherwise

3.5.4 Aggregate Impact Value (IS: 2386 Part IV)

- Indicates toughness
- Limit: < 45% for pavement, < 30% for wearing surfaces

3.5.5 Los Angeles Abrasion Test (IS: 2386 Part IV)

- Measures wear resistance
- Limit: < 30% for high-quality concrete

3.5.6 Soundness Test

- Assesses resistance to weathering (freeze-thaw or chemical attack)
- Carried out using sodium/magnesium sulfate solutions

3.5.7 Alkali-Aggregate Reactivity (AAR)

- Some aggregates react with alkalis in cement causing expansion and cracking

- Mitigation: Use of pozzolans, low-alkali cement

3.6 Role of Aggregates in Concrete

- **Strength**: Coarse aggregates provide strength and stiffness.
- **Workability**: Fine aggregates influence ease of placement.
- **Durability**: Properly graded and sound aggregates improve life span.
- **Economy**: Aggregates are cheaper than cement and reduce cost.
- **Thermal Resistance**: Some aggregates enhance heat resistance.

3.7 Influence of Aggregate Characteristics on Concrete Properties

Aggregates influence not just the strength and workability of concrete, but also critical performance parameters like permeability, shrinkage, and resistance to aggressive environments.

3.7.1 Surface Texture

- **Smooth Aggregates**: Lower bond with cement paste → Reduced strength. Example: River gravels.
- **Rough Aggregates**: Higher mechanical interlock → Enhanced bond strength. Example: Crushed basalt or granite.

3.7.2 Absorption and Moisture Content

- Aggregates with **high absorption** require water correction during mix design.
- **Free moisture** contributes additional water to the mix and affects the effective water-cement ratio.

Moisture States of Aggregates:

- Bone dry
- Air dry
- Saturated Surface Dry (SSD)
- Wet (with surface moisture)

3.7.3 Maximum Size of Aggregates

- Larger size → Reduced water and cement requirements (for same workability)
- Smaller size → Better surface area for bond, increased strength
- Limitation:
  - Should not exceed 1/4 of the minimum member thickness
  - Should not be more than 20 mm for thin sections or pumpable concrete

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3.8 Aggregate Handling and Storage

Improper storage and handling can lead to:

- Segregation
- Contamination with clay, silt, oil, or chemicals
- Excessive moisture variation

Best Practices:

- Store coarse and fine aggregates separately
- Use hard, dry, sloped platforms or bins with retaining walls
- Cover aggregates during rains
- Avoid direct contact with soil or organic materials

3.9 Deleterious Materials in Aggregates

Certain materials in aggregates can adversely affect concrete performance.

3.9.1 Types of Deleterious Substances

Deleterious Material	Effects on Concrete
Clay and silt	Weakens bond with cement, increases water demand
Organic impurities	Retards setting and hardening
Soft fragments	Reduces strength
Salts (chlorides/sulfates)	Corrosion of steel, efflorescence

Deleterious Material	Effects on Concrete
Coal and lignite	Discoloration and poor durability
Alkali-reactive particles	Causes expansion and cracking

Permissible Limits (IS: 383):

- Clay lumps: <1%
- Soft particles: <3%
- Organic impurities: Should pass color test with NaOH solution

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3.10 Alkali-Aggregate Reaction (AAR)

AAR is a chemical reaction between reactive silica in aggregates and alkali hydroxides in cement, leading to expansive gel formation.

Types of AAR

1. **Alkali-Silica Reaction (ASR)**
    - Most common
    - Requires reactive silica, moisture, and alkalis
2. **Alkali-Carbonate Reaction (ACR)**
    - Less common
    - Involves specific dolomitic rocks

Consequences

- Cracking and spalling
- Loss of durability and aesthetics
- Reduced load-carrying capacity

Preventive Measures

- Use low-alkali cement ($Na_2Oeq < 0.6\%$)
- Use non-reactive aggregates
- Add pozzolanic materials (fly ash, slag, silica fume)
- Control moisture ingress

3.11 Use of Recycled Aggregates

Recycled aggregates are obtained from construction and demolition (C&D) waste.

Sources:

- Demolished buildings
- Rejected precast elements
- Waste concrete

Properties Compared to Natural Aggregates:

Property	Recycled Aggregate	Natural Aggregate
Water absorption	Higher	Lower
Density	Lower	Higher
Strength	Lower (typically 70–90%)	Higher
Environmental impact	Lower	Higher (due to mining)

Applications:

- Non-structural concrete
- Pavements and base layers
- Lean concrete mixes

IS 383:2016 now includes specifications for recycled aggregates.

3.12 Eco-Friendly and Alternative Aggregates

To reduce the carbon footprint of concrete and conserve natural resources, sustainable aggregate options are explored:

Examples:

- **Manufactured Sand (M-Sand):**
  - Crushed from hard stones, replaces natural river sand
  - Finer control on grading, better consistency
- **Blast Furnace Slag (BFS):**
  - By-product from steel industry

    - Good for mass concrete and pavement blocks
- **Expanded Clay, Shale, or Slate:**
    - Lightweight
    - Used in precast blocks and panels
- **Palm Kernel Shells / Coconut Shells:**
    - Agricultural waste used as lightweight coarse aggregate in rural housing

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3.13 Codal Provisions Related to Aggregates (IS Codes)

Code	Title
IS 383:2016	Specification for Coarse and Fine Aggregates from Natural Sources
IS 2386 (Parts I–VIII)	Methods of Test for Aggregates
IS 456:2000	Plain and Reinforced Concrete – Code of Practice
IS 10262:2019	Guidelines for Concrete Mix Design
IRC: SP: 63	Guidelines for Use of Waste Plastic in Hot Bituminous Mixes

3.14 Quality Control of Aggregates in Site Practice

Checklist for Field Engineers:

- Check for visible clay lumps, vegetation, or contamination
- Observe moisture content daily and adjust mix water
- Confirm sieve analysis compliance with mix design
- Ensure proper storage (no mixing of sizes or sources)
- Randomly test aggregate properties if batch plant is off-site

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