Chapter 5: Aggregates – Properties, Grading, Testing

Introduction

Aggregates are inert granular materials such as sand, gravel, crushed stone, or recycled concrete used in construction. They form the bulk of cement concrete and occupy about 70%–80% of the total volume of concrete. The quality, size, texture, shape, and grading of aggregates significantly influence the strength, durability, and workability of concrete. Understanding the characteristics and testing procedures for aggregates is essential for civil engineers to design and ensure durable and cost-effective structures.

5.1 Classification of Aggregates

Aggregates can be classified based on the following criteria:

A. Based on Size

1. **Fine Aggregates**: Particles passing through a 4.75 mm IS sieve and retained on a 75-micron sieve. (e.g., natural sand, crushed stone sand).
2. **Coarse Aggregates**: Particles retained on a 4.75 mm IS sieve. (e.g., gravel, crushed stone).

B. Based on Origin

1. **Natural Aggregates**: Obtained from natural sources like river beds, quarries, and pits (sand, gravel).
2. **Artificial Aggregates**: By-products or specifically manufactured materials (e.g., blast furnace slag, lightweight expanded clay aggregate).
3. **Recycled Aggregates**: Derived from demolished concrete and construction waste.

C. Based on Shape

1. **Rounded Aggregates**: Naturally weathered and smooth (e.g., river gravel).
2. **Irregular Aggregates**: Partially shaped, offering better bond than rounded.

3. **Angular Aggregates**: Rough and sharp-edged, ideal for high-strength concrete.
4. **Flaky and Elongated Aggregates**: Flat or needle-like, undesirable due to poor interlocking and high surface area.

D. Based on Density

1. **Normal Weight Aggregates**: 1520–1680 kg/m³ (e.g., granite, basalt).
2. **Lightweight Aggregates**: <1120 kg/m³ (e.g., pumice, vermiculite).
3. **Heavyweight Aggregates**: >2000 kg/m³ (e.g., barite, magnetite) used for radiation shielding.

5.2 Properties of Aggregates

5.2.1 Physical Properties

1. Size and Shape

- Influences workability, packing, and strength of concrete.
- Angular aggregates offer better interlock and strength, but lower workability.

2. Surface Texture

- Affects the bond between cement paste and aggregate.
- Rough-textured aggregates provide stronger bonds.

3. Specific Gravity

- Ratio of the weight of a given volume of aggregate to the weight of an equal volume of water.
- **Apparent Specific Gravity**: Excludes water in pores.
- **Bulk Specific Gravity**: Includes water in permeable pores.
- Normal range: 2.4 – 2.9.

4. Water Absorption

- Ability to absorb water into pores, expressed as a percentage of dry weight.
- Indicates porosity and affects mix water content.

5. Moisture Content

- Total water present in aggregates; may be in absorbed, surface, or free form.

6. Bulk Density

- Weight of aggregate in a unit volume (kg/m³), used for batching.

- Loose and compacted densities are considered.

*7. **Voids Content***

- Percentage of space between aggregate particles.
- Helps in mix design by estimating paste volume required.

5.2.2 Mechanical Properties

*1. **Crushing Strength (Aggregate Crushing Value - ACV)***

- Measures resistance to crushing under gradually applied compressive load.
- Lower ACV (<30%) is desirable for concrete roads.

*2. **Impact Strength (Aggregate Impact Value - AIV)***

- Measures resistance to sudden shock or impact.
- Lower AIV (<20%) preferred for concrete pavement.

*3. **Abrasion Resistance (Los Angeles Abrasion Value - LAAV)***

- Indicates resistance to wear and tear due to friction.
- LAAV < 30% is ideal for most structural applications.

*4. **Ten Percent Fines Value***

- Load required to produce fines equal to 10% of total sample weight.
- Useful alternative to ACV.

5.2.3 Thermal and Chemical Properties

*1. **Thermal Expansion***

- Aggregates must be compatible with cement paste in thermal expansion behavior to avoid cracking.

*2. **Chemical Stability***

- Must resist chemical attacks (e.g., alkali-aggregate reaction).
- Reactive silica can cause expansion and cracking over time.

*3. **Soundness***

- Ability to resist weathering or cycles of wetting and drying, freezing and thawing.
- Tested using sodium sulfate or magnesium sulfate.

5.3 Grading of Aggregates

Grading refers to the distribution of particles of different sizes in an aggregate sample.

5.3.1 Objectives of Good Grading

- Reduce void content in concrete.
- Ensure workability and durability.
- Reduce cement consumption.
- Achieve maximum density.

5.3.2 Types of Grading

1. **Uniform Grading**: Aggregates of similar size – higher voids, less stability.
2. **Gap Grading**: Missing intermediate sizes – prone to segregation.
3. **Well Graded**: Properly distributed sizes – dense and strong concrete.

5.3.3 Grading Limits and Zones

As per IS:383-2016, fine aggregates are classified into four grading zones (Zone I to IV). Coarse aggregate grading depends on nominal size (10 mm, 20 mm, etc.) with specified limits on sieve analysis.

5.4 Testing of Aggregates

5.4.1 Sieve Analysis

- Determines particle size distribution.
- Aggregates are passed through standard IS sieves, and weight retained on each sieve is recorded.

5.4.2 Specific Gravity and Water Absorption (IS 2386 Part III)

- Pycnometer method or wire basket method used.
- Determines porosity and absorption characteristics.

5.4.3 Aggregate Crushing Value Test (IS 2386 Part IV)

- Cylinder filled with aggregate and subjected to compressive load.
- Percentage of crushed material gives ACV.

5.4.4 Aggregate Impact Value Test

- Sample placed in a cylindrical cup and subjected to 15 blows from a hammer.
- Measures resistance to impact.

5.4.5 Los Angeles Abrasion Test (IS 2386 Part IV)

- Aggregate subjected to abrasion and impact in a rotating drum with steel balls.
- Percentage wear indicates resistance to abrasion.

5.4.6 Flakiness and Elongation Index Test

- Determines shape characteristics.
- Flaky: thickness $< 0.6 \times$ mean size.
- Elongated: length $> 1.8 \times$ mean size.

5.4.7 Soundness Test

- Repeated cycles of soaking in sodium/magnesium sulfate solution and drying.
- Assesses resistance to weathering.

5.4.8 Alkali-Aggregate Reactivity Test

- Mortar bars made with aggregate are stored in hot water to monitor expansion.
- High expansion indicates reactive aggregates.

5.4.9 Bulk Density and Voids

- Measured using cylindrical container.
- Helps estimate mix proportions.

5.4.10 Moisture Content Test

Objective: To determine the amount of water present in an aggregate sample, which is critical for accurate water-cement ratio adjustments in concrete mix design.

Methods:

1. **Oven Drying Method**:

- Sample is weighed, then dried in an oven at 100–110°C for 24 hours, and weighed again.
- Moisture content (%) =

$$\frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}} \times 100$$

2. **Calcium Carbide Method**:
   - Portable and quick.
   - Calcium carbide reacts with moisture to form acetylene gas, and pressure developed is used to estimate moisture.
3. **Infrared/Microwave Method**:
   - Rapid and suitable for site conditions using portable devices.

5.4.11 Deleterious Materials Test (IS 2386 Part II)

Objective: To identify and measure harmful substances in aggregates that may impair concrete durability.

Common Deleterious Materials:

- Clay lumps and friable particles
- Silt and dust
- Organic impurities (e.g., humus)
- Soft fragments
- Coal, lignite, or mica

Test Methods:

- **Organic Impurities Test**: Sand is mixed with sodium hydroxide solution; color compared with standard solution to detect presence of organic matter.
- **Clay and Fine Silt Test**: Washed through 75-micron sieve; percentage determined by sedimentation or washing.

5.4.12 Alkali-Silica Reactivity (ASR) Test

Overview:

- A long-term chemical reaction between alkalis (Na_2O, K_2O) in cement and reactive silica in aggregates.
- Produces expansive gel, leading to cracking, pop-outs, and structural failure.

Test Method (ASTM C1260):

- Mortar bars with suspect aggregates are immersed in NaOH solution at 80°C.
- Expansion measured at 14 days; if >0.1%, the aggregate is considered potentially reactive.

5.4.13 Petrographic Examination (IS 2386 Part VIII)

Purpose: To microscopically examine the mineral composition and texture of aggregates to detect harmful constituents and understand durability.

Method:

- Thin sections of aggregates prepared and analyzed under polarizing microscope.
- Especially useful in identifying reactive minerals such as opal, chalcedony, or strained quartz.

5.5 Field Considerations and Storage of Aggregates

5.5.1 Aggregate Handling

Improper handling may lead to:

- Segregation of particle sizes.
- Contamination with soil, organic matter, or chemicals.

Preventive Measures:

- Use rubber belt conveyors and controlled discharge chutes.
- Avoid dropping from excessive heights.

5.5.2 Storage of Aggregates

Guidelines:

- Stored on clean, hard, and dry platforms or slabs.
- Use partitions for different sizes/types.
- Maintain proper drainage to prevent waterlogging.
- Avoid mixing recycled aggregates with natural ones unless specified.

5.5.3 Batching and Mixing Considerations

- Aggregate moisture directly affects water-cement ratio.
- Moisture corrections are necessary before batching to avoid over-watering or under-watering.
- Aggregates should be free-flowing and non-cohesive for consistent batching.

5.6 Use of Recycled and Alternative Aggregates

5.6.1 Recycled Aggregates

Sources:

- Demolished concrete, asphalt pavements, construction waste.

Advantages:

- Environmentally friendly.
- Reduces landfill usage and natural resource consumption.

Challenges:

- Variable quality.
- Higher water absorption and lower strength.

5.6.2 Manufactured Sand (M-sand)

Produced by: Crushing rocks (granite, basalt, etc.) into fine particles.

Benefits:

- Consistent quality.
- Reduced environmental impact of river sand mining.

Issues:

- Needs strict grading control.
- May require more water or admixtures in concrete.

5.6.3 Lightweight Aggregates

Examples:

- Expanded clay, shale, perlite, pumice.

Uses:

- Thermal insulation.
- Structural lightweight concrete.

5.6.4 Heavyweight Aggregates

Examples:

- Barite, hematite, magnetite, iron punchings.

Applications:

- Radiation shielding in nuclear plants or X-ray rooms.
