THE UNIVERISTY OF ZAMBIA

School of Engineering

Department of Civil and Environmental Engineering

CEE 3111 - CIVIL ENGINEERING MATERIALS AND CONSTRUCTION PRACTICES

2023 ACADEMIC YEAR

SEMESTER 1

TOPIC 3

Concrete and its constituents

General Introduction

What is Concrete?

- Composite building material composed of fine and coarse aggregate bonded together with a fluid cement (cement paste) that hardens over time

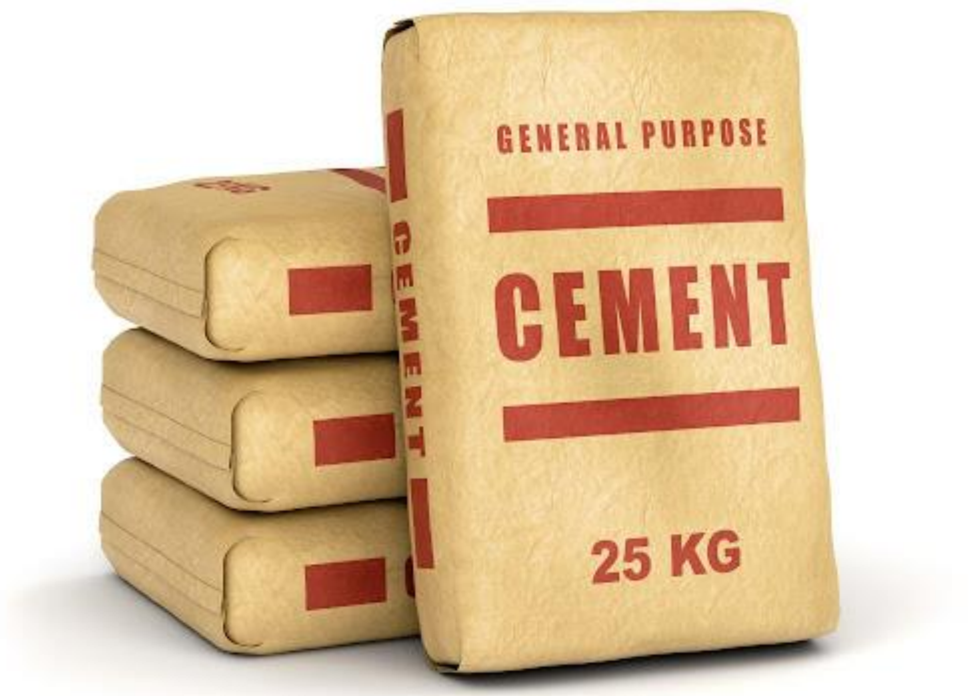
- Low tensile strength, its high compressive strength

Basic constituents of concrete

1. Cement
2. Aggregates
3. Water
4. Admixtures (superplasticizers, air entraining agents, etc.) and
5. Air

Cement

Background



- History of cementing material is as old as the history of engineering construction
- Cementing materials used by Egyptians, Romans and Indians in their ancient constructions obtained by burning gypsum and limestones
- Main use of cement:
  - ✓ Making concrete
  - ✓ Stabilizing soils and aggregate

Manufacture of Portland Cement

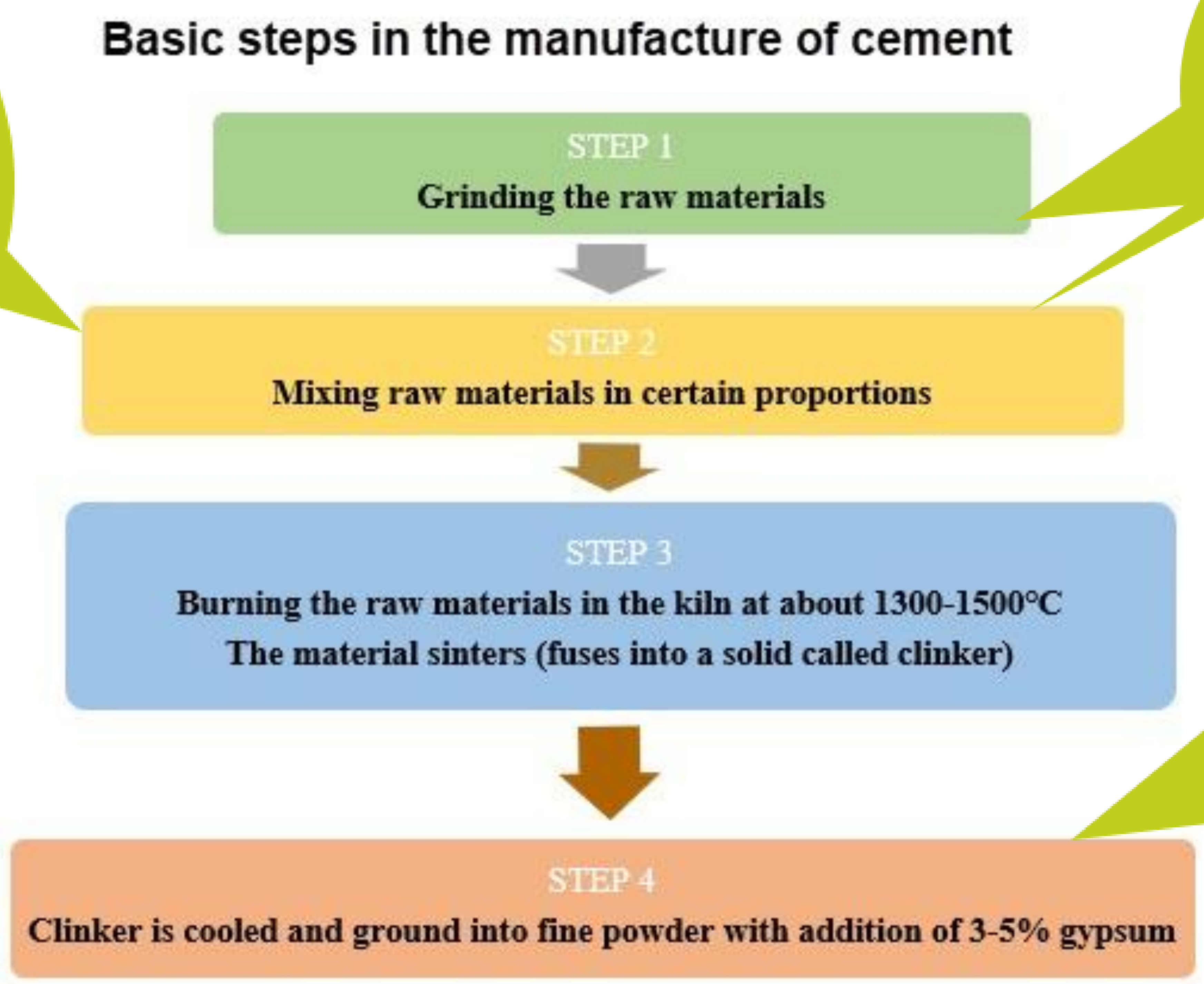
The raw materials required include:

- Limestone or chalk
- Argillaceous materials such as clay and shale

Cement – Manufacturing Process

- Manufacturing process involves:

Mainly lime, silica, alumina, and iron oxide



If steps 1 and 2 (grinding and mixing of raw materials) are done in wet conditions, the process is called 'Wet Process.' Else, it is a 'Dry Process'

In step 4, the rate of cooling of the clinker influences the degree of crystallization and size of the crystal. Slow rate of cooling of the clinker results in higher strength of cement

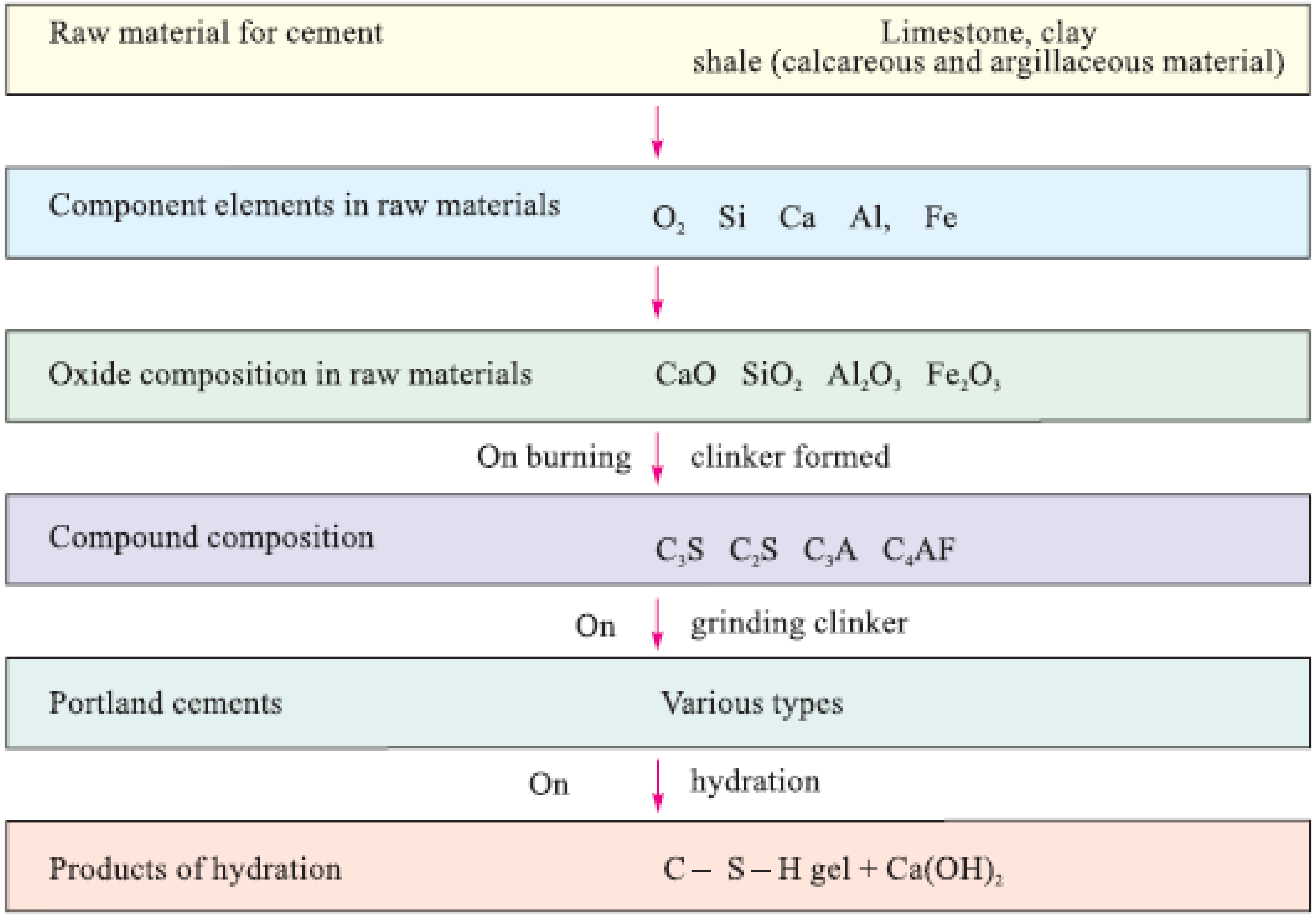
Cement

Chemical Composition of 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

Cement - Hydration

- Cement acquires adhesive properties when it chemically combines with water.
- Cement + Water = Hydration of cement (Exothermic)
- Due to drying shrinkage and temperature variation, microcracks develop even before a structure is loaded



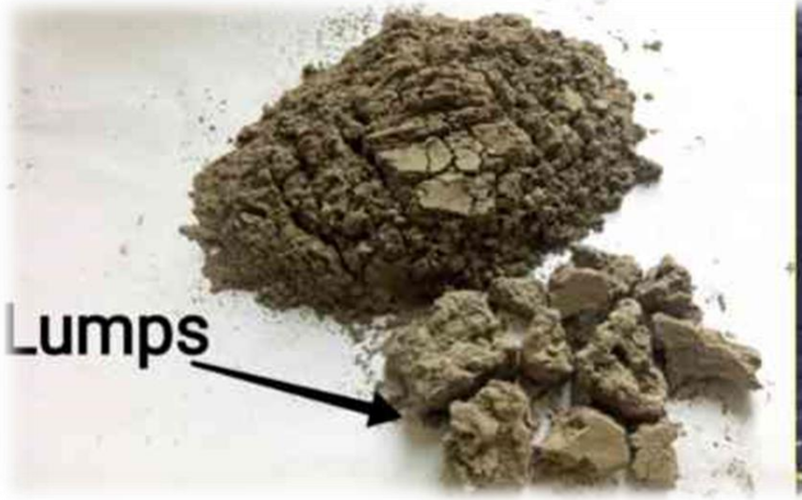
Products of Hydration

Cement – Types of Cement

- Portland and Non-Portland cements are generally used include:
  - ✓ Ordinary Portland cement
  - ✓ Rapid hardening cement
  - ✓ Air entraining cement
  - ✓ Very high strength
- ASTM classifies cements different categories (Type I through to Type V), depending on the use.

Cement – Tests for Cement

- Two categories
  - Field Testing
  - Laboratory Testing




Field Testing

✓ When you open the bag and take a look, there should be no visible lumps

✓ Feel a pinch of cement between your fingers. It should give a smooth and not gritty feeling

✓ Take a handful of cement and throw it on a bucket full of water. The particles should float for some time before they start sinking

Cement – Tests for Cement

Laboratory testing cement

- Tests include:

Fineness test:

- Conducted to establish if the cement has coarse particles
  - ✓ sieve test (No. 325 =45 for ASTM C430) or
  - ✓ Air permeability method

Specific Gravity of test:

- Needed for mixture-proportioning calculations

Soundness test:

- Refers to the ability of cement to retain its volume after setting.

Cement – Tests for Cement

Setting time test

✓ Initial & Final setting times.

Compressive strength test of mortar

✓ Usually, 1 part of cement to 3 parts of fine aggregate

Chemical composition test

- Conducted to ensure that percentage of each of the raw materials is according to specification for specified type of cement.

- The general equation is given below:

$$\frac{CaO - 0.7\,SO_3}{2.8\,SiO_2 + 1.2\,Al_2O_3 + 0.65\,Fe_2O_3}$$: Not greater than 1.02 and not less than 0.66

Cement – Tests for Cement

Heat of hydration test

- Conducted to ensure that exothermic chemical reaction between cement and water is controlled.
- Reaction of tricalcium aluminate with water liberates large amounts of heat.
- This heat causes serious expansion in massive constructions such as dams and mat foundations.
- Subsequent cooling causes considerable shrinkage that results in cracking of concrete.
- Gypsum is used to slow down the rate of aluminate hydration. It produces sulfate ions that suppress the solubility of the aluminates

Cement - Characteristics

Sl. No.	Type of Cement	Fineness (m^2/kg) Min.	Soundness By Le chatelier (mm) Max.	Soundness By Autoclave (%) Max.	Setting Time Initial (mts) min.	Setting Time Final (mts) max.	Compressive Strength 1 Day min. MPa	Compressive Strength 3 Days min. MPa	Compressive Strength 7 Days min. MPa	Compressive Strength 28 Days min. MPa
1.	33 Grade OPC (IS 269-1989)	225	10	0.8	30	600	N S	16	22	33
2.	43 Grade OPC (IS 8112-1989)	225	10	0.8	30	600	N S	23	33	43
3.	53 Grade OPC (IS 12269-1987)	225	10	0.8	30	600	N S	27	37	53
4.	SRC (IS 12330-1988)	225	10	0.8	30	600	N S	10	16	33
5.	PPC (IS 1489-1991) Part I	300	10	0.8	30	600	N S	16	22	33
6.	Rapid Hardening (IS 8041-1990)	325	10	0.8	30	600	16	27	N S	N S
7.	Slag Cement (IS 445-1989)	225	10	0.8	30	600	N S	16	22	33
8.	High Alumina Cement (IS 6452-1989)	225	5	N S	30	600	30	35	N S	N S
9.	Super Sulphated Cement (IS 6909-1990)	400	5	N S	30	600	N S	15	22	30
10.	Low Heat Cement (IS 12600-1989)	320	10	0.8	60	600	N S	10	16	35
11.	Masonry Cement (IS 3466-1988)	*	10	1	90	1440	N S	N S	2.5	5
12.	IRS-T-40	370	5	0.8	60	600	N S	N S	37.5	N S

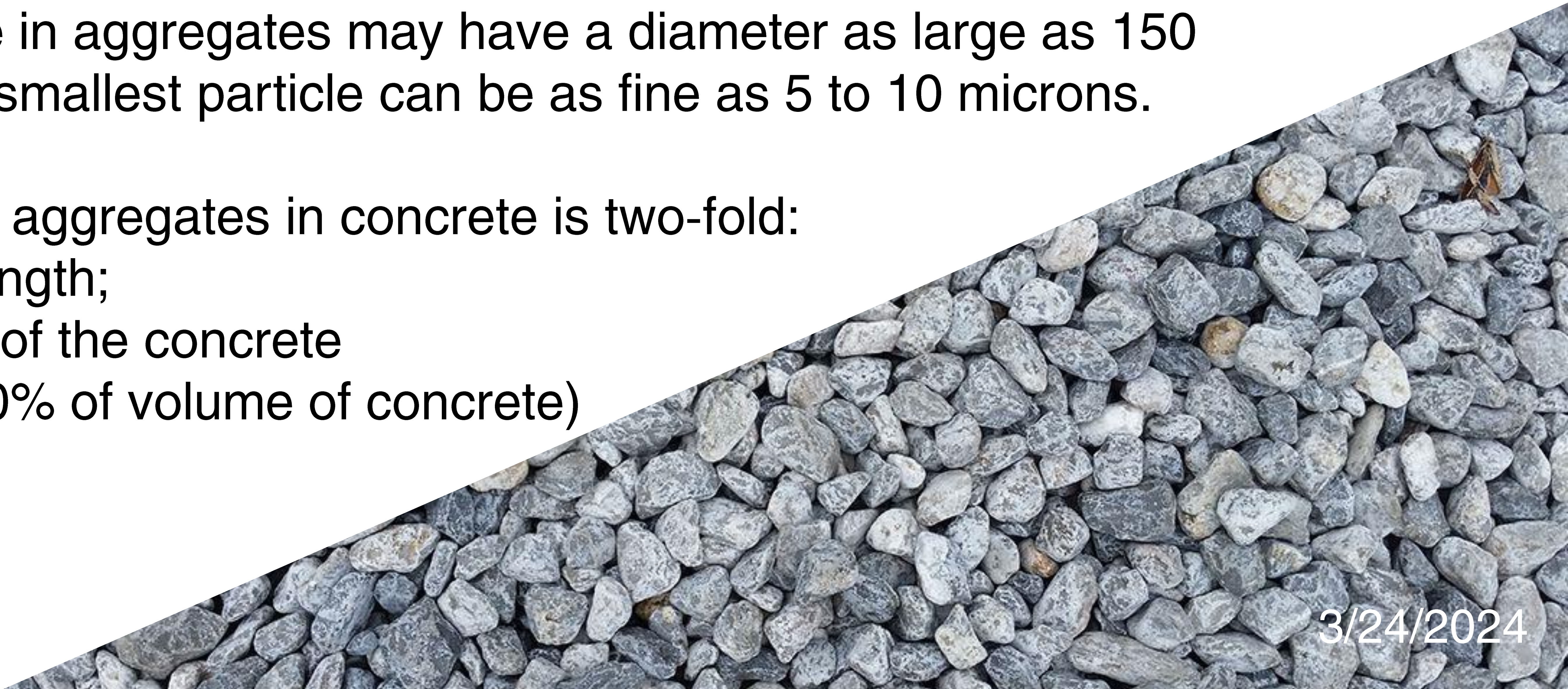
Aggregates - Classification

Classification

- In civil engineering, the term aggregate means a mass of crushed stone, gravel, sand, etc., predominantly composed of individual particles, but in some cases including clays and silts

- Largest particle size in aggregates may have a diameter as large as 150 mm (6 in.), and the smallest particle can be as fine as 5 to 10 microns.

- The benefit of using aggregates in concrete is two-fold:
  - ✓ Increase the strength;
  - ✓ Reduce the cost of the concrete
    - ✓ (Occupy 70-80% of volume of concrete)



Aggregates - Types

- Two main groups, with respect to size:
  - ✓ Coarse aggregates - (gravel, etc.) - retained on a 4.75 mm sieve
  - ✓ Fine aggregates - passing a 4.75 mm sieve (No. 4) e.g. sand

- Fine and coarse aggregates must be proportioned (gradation of the aggregates) very well so that the amount of void space (air) in the concrete can be minimized.

- This is achieved by using sieve analysis tests and gradation curves.

- Aggregates must be clean (dust and salt free). If not, they have to be washed before mixing.

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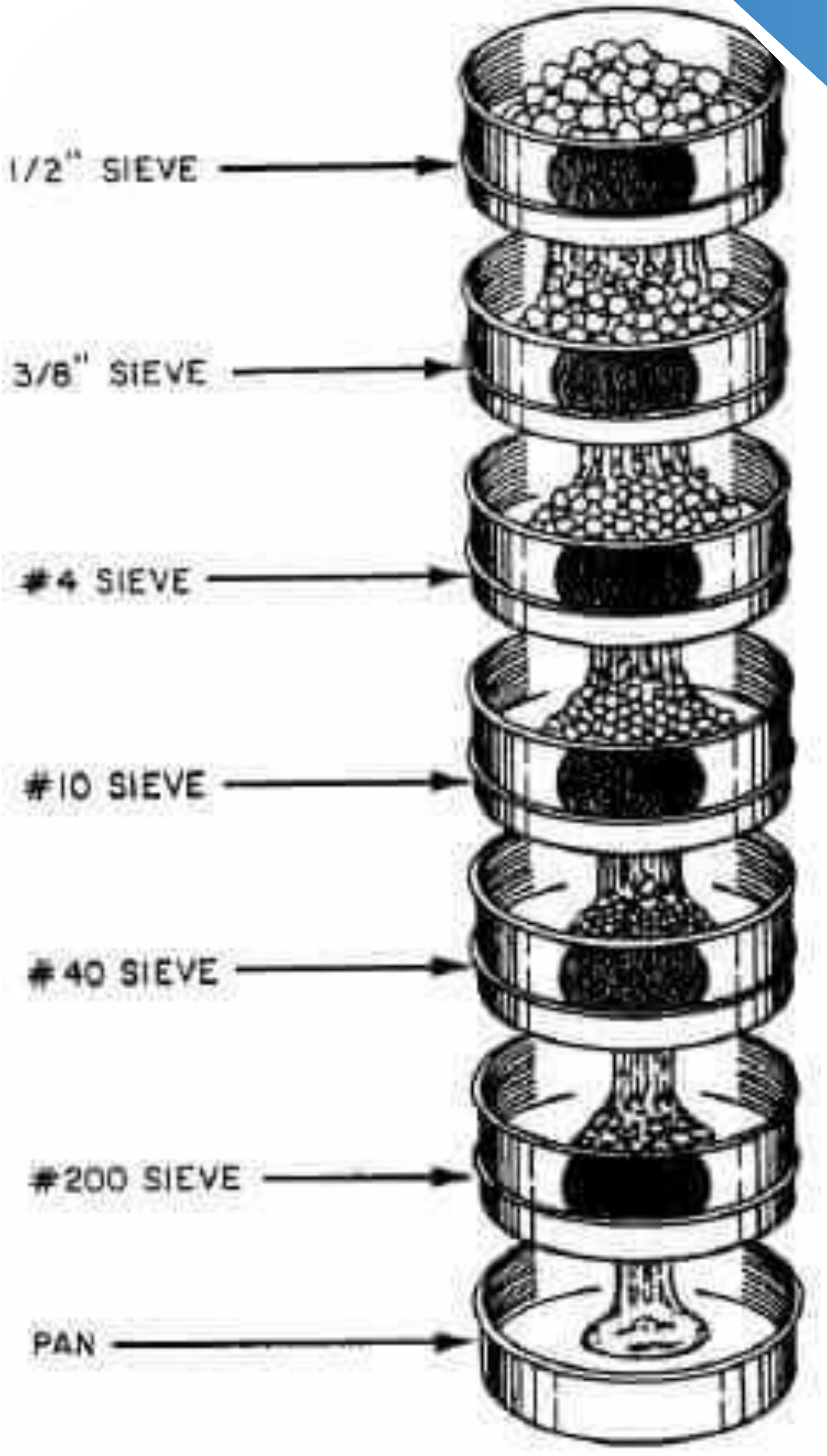


Aggregates - Sources

Two common sources:

- **Natural Aggregates** - gravel pits, river run deposits, and rock quarries
  - ✓ sand,
  - ✓ gravel,
  - ✓ crushed stones, etc.)

- **Artificial or Manufactured Aggregates** - man-made
  - ✓ broken brick,
  - ✓ air-cooled slag,
  - ✓ Sintered (compacted) fly ash,
  - ✓ bloated clay – clay caused to swell

Aggregates - Properties

- Can be described by:
  1. Physical characteristics , 2. Chemical characteristics,
  3. Mechanical characteristics

Aggregates – Physical Properties

Property	Relative Importance for End Use*		
	Portland Cement Concrete	Asphalt Concrete	Base
PHYSICAL			
Particle shape (angularity)	M	V	V
Particle shape (flakiness, elongation)	M	M	M
Particle size—maximum	M	M	M
Particle size—distribution	M	M	M
Particle surface texture	M	V	V
Pore structure, porosity	V	M	U
Specific gravity, absorption	V	M	M
Soundness—weatherability	V	M	M
Unit weight, voids—loose, compacted	V	M	M
Volumetric stability—thermal	M	U	U
Volumetric stability—wet/dry	M	U	M
Volumetric stability—freeze/thaw	V	M	M
Integrity during heating	U	M	U
Deleterious constituents	V	M	M

*V = Very important; M = Moderately important; U = Unimportant or importance unknown

Aggregates – Chemical Properties

Property	Relative Importance for End Use*		
	Portland Cement Concrete	Asphalt Concrete	Base
CHEMICAL			
Solubility	M	U	U
Surface charge	U	V	U
Asphalt affinity	U	V	M
Reactivity to chemicals	V	U	U
Volume stability—chemical	V	M	M
Coatings	M	M	U

*V = Very important; M = Moderately important; U = Unimportant or importance unknown

Aggregates – Mechanical Properties

Property	Relative Importance for End Use*		
	Portland Cement Concrete	Asphalt Concrete	Base
MECHANICAL			
Compressive strength	M	U	U
Toughness (impact resistance)	M	M	U
Abrasion resistance	M	M	M
Character of products of abrasion	M	M	U
Mass stability (stiffness, resilience)	U	V	V
Polishability	M	M	U

*V – Very important; M – Moderately important; U – Unimportant or importance unknown

Aggregates – Properties

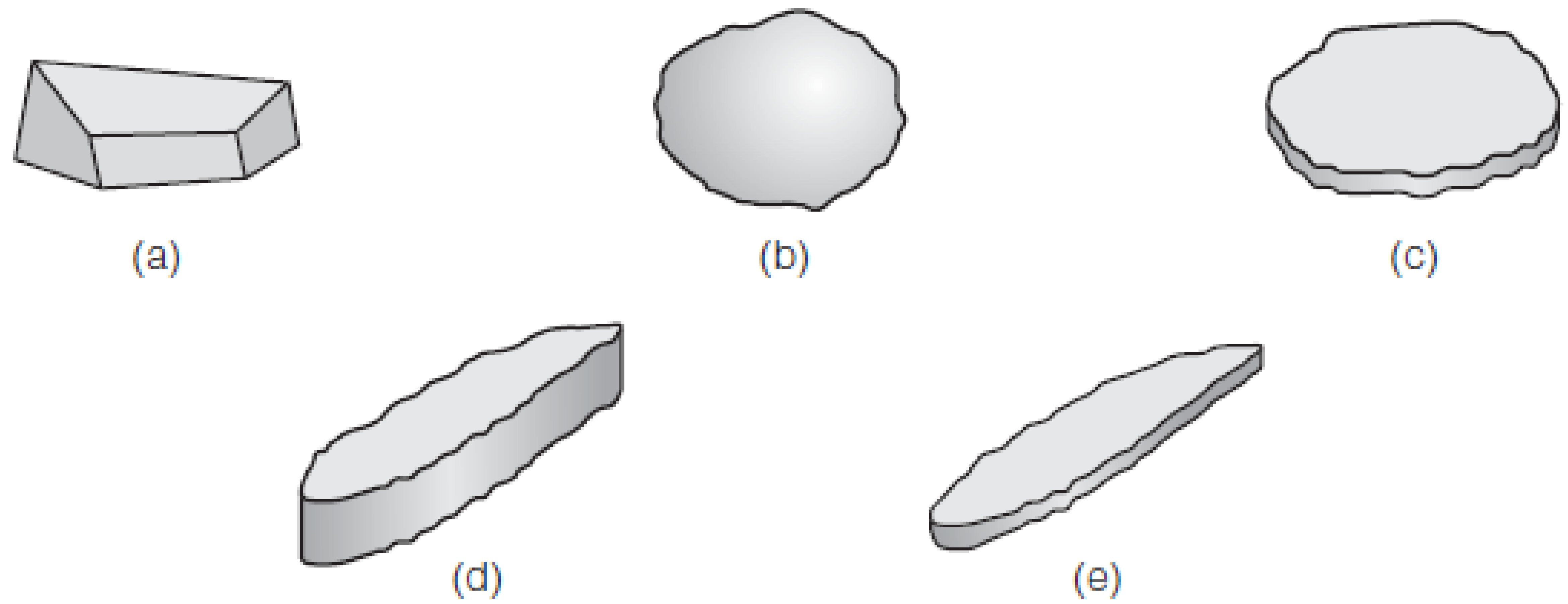
1. Angularity
   - ✓ Defines sharpness of aggregate surface
   - ✓ Angular aggregates sharp corners and rough texture.
   - ✓ Rounded aggregates have smooth curved surface texture.

- Angular & rough-textured aggregates have higher stability than rounded, smooth-textured aggregates.

- Angular aggregates are more difficult to work into place than rounded aggregates, since their shapes make it difficult for them to slide across each other.

Aggregates – Properties

2. Flakiness – Also referred to as flat and elongated, describes the relationship between the dimensions of the aggregate



(a) angular (b) rounded (c) flaky (d) elongated (e) flaky and enlongated

Aggregates – Properties

3. Maximum and Nominal Particle Size

- **Maximum particle size** - smallest sieve through which 100 percent of the aggregates pass.

- **Nominal maximum aggregate size** - the largest sieve that retains any of the aggregate, but generally not more than 10 percent.

Sieve Size	percent passing
37.5 mm	100
25 mm	95-100
12.5 mm	25-60
4.75 mm	0-10
2.36 mm	0-5

In this example, maximum aggregate size is 37.5 mm and a nominal maximum size of 25.0 mm

4. Texture of coarse aggregates

✓ Rough
✓ Smooth

Aggregates – Properties

5. Soundness and Durability

- The ability of aggregate to withstand weathering is defined as soundness or durability.

- Aggregates used in various civil engineering applications must be sound and durable, particularly if the structure is subjected to severe climatic conditions.

- Water freezing in the voids of aggregates generates stresses that can fracture the stones.

6. Toughness, Hardness, and Abrasion Resistance

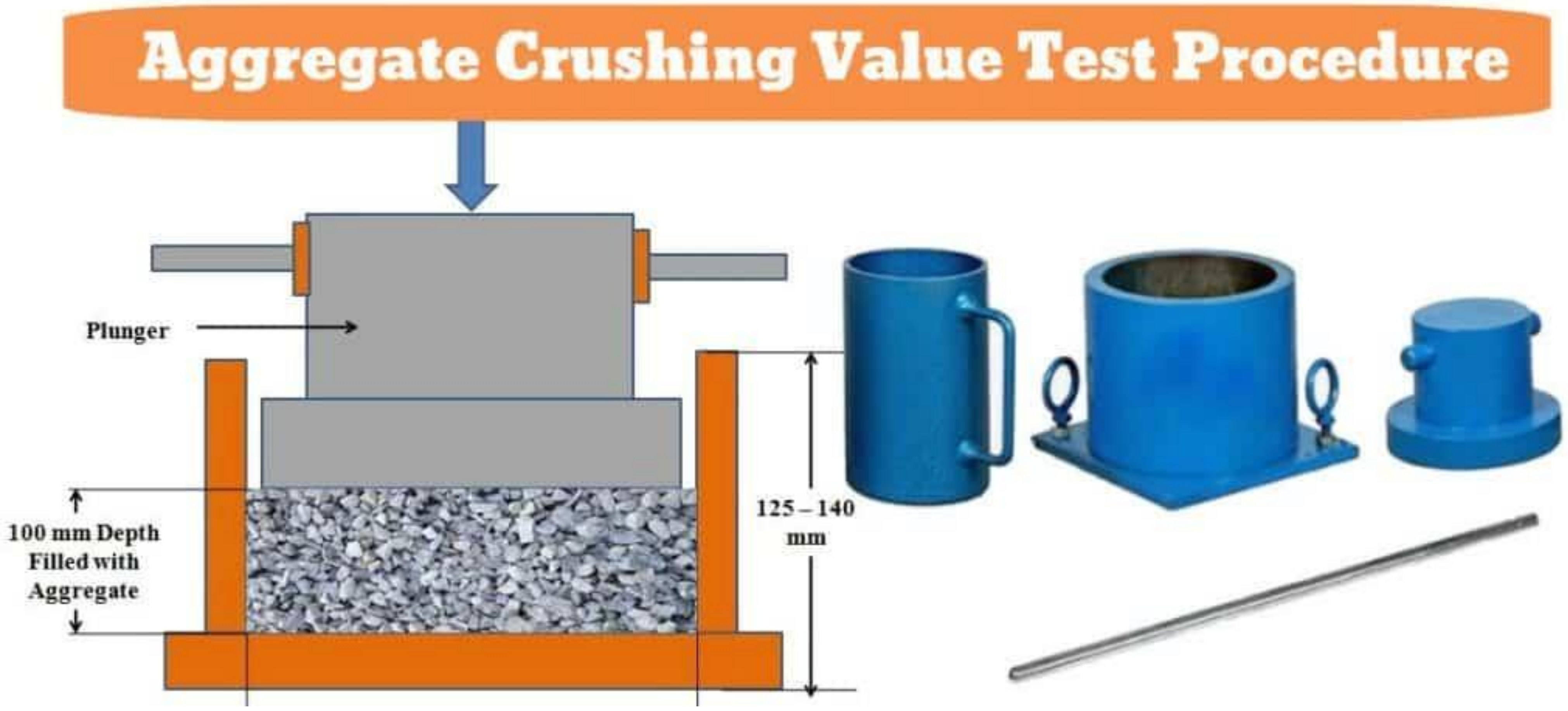
- Toughness - ability of aggregates to resist the damaging effect of loads
- LAA (ASTM C131, C535) evaluates the aggregates' toughness and abrasion resistance

Aggregates – Properties

7. Strength of Aggregates

- Aggregate strength is generally important in high-strength concrete and in the surface course on heavily traveled pavements.

- Aggregate Crushing Value (ACV) gives the relative strength of the parent rock of the aggregate

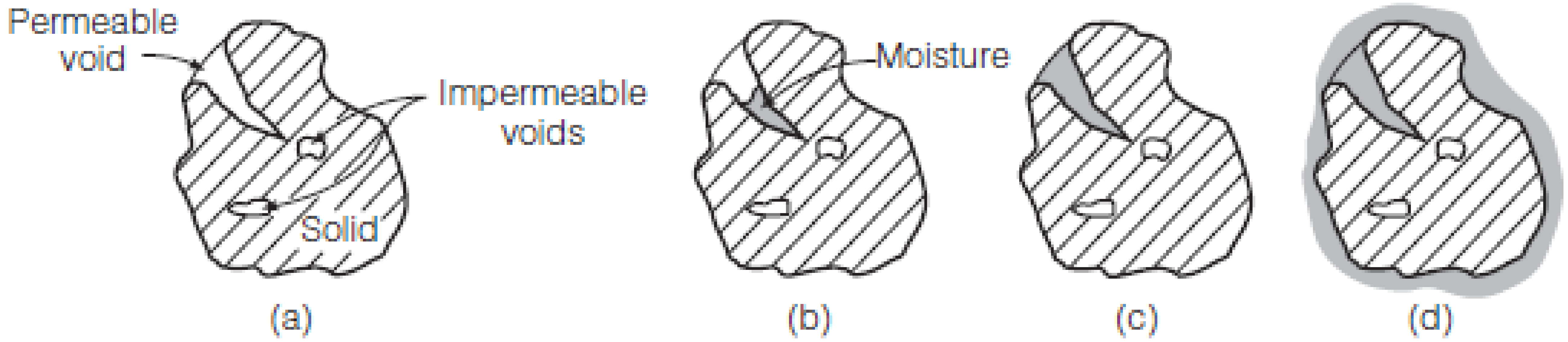


Aggregates – Properties

8. Absorption

- Although aggregates are inert, they can capture water and asphalt binder in surface voids.
- The amount of water the aggregates absorb is important in the design of Portland cement concrete, since moisture captured in the aggregate voids is not available to react with the cement or to improve the workability of the plastic concrete
- Aggregate absorption must be evaluated to determine the appropriate amount of water to mix into the concrete.
- Absorption is also important for asphalt concrete, since absorbed asphalt is not available to act as a binder.
- Highly absorptive aggregates require greater amounts of asphalt binder, making the mix less economical

Aggregates - Properties



(a) bone dry (b) air dry (c) saturated surface dry (SSD) (d) moist

- **Bone dry** - aggregate contains no moisture - this requires drying the aggregate in an oven to a constant mass
- **Air dry condition** - aggregate may have some moisture but the saturation state is not quantified

Aggregates – Properties

- **Saturated Surface-Dry (SSD)** condition - aggregate's permeable voids are filled with moisture but the main surface area of the aggregate particles is dry
- Absorption is defined as the moisture content in the SSD condition
- Moist aggregates have moisture content in excess of the SSD condition
- Free moisture is the difference between the actual moisture content of the aggregate and the moisture content in the SSD condition.

$$\boldsymbol{Moisture\ Content}\ (MC) = \frac{W_{moist} - W_{dry}}{W_{dry}} \times 100\%$$

$$\boldsymbol{Absorption} = \frac{W_{SSD} - W_{dry}}{W_{dry}} \times 100\%$$

Aggregates - Properties

Absorption - Example

A sample of sand has the following properties:

Absorption = 1.6% : Dry mass = 589.9g : Moist mass = 625.2g

Determine: (a) total moisture content, and (b) free moisture content (c) Mass at SSD condition

$$Total\ MC = \frac{W_{moist} - W_{dry}}{W_{dry}} \times 100\% = \frac{625.2g - 589.9g}{589.9g} \times 100\% = 6\%$$

$$Free\ MC = MC - Absorption = 6\% - 1.6\% = 4.4\%$$

$$Mass\ at\ SSD = Absorption(DP) \times W_{dry} + W_{dry} = 0.016 \times 589.9 + 589.9 = 599.34$$

Aggregates - Properties

9. Specific Gravity

- Important for concrete mix design
  - ✓ Density, the mass per unit volume can be used in these calculations
  - ✓ Specific gravity (Sp.Gr.), the mass of a material divided by the mass of an equal volume of distilled water, is more commonly used.

- Four types of specific gravity are defined based on how voids in the aggregate particles are considered.

$$\boldsymbol{Bulk-dry\ Sp.Gr} = \frac{Dry\ weight}{[Total\ particle\ volume] \times \gamma_w}$$

$$= \frac{Dry\ weight\ of\ solid\ (W_s)}{\left[Volume\ of\ solids\ (V_s) + Volume\ of\ water\ impermeable\ voids\ (V_i) + Volume\ of\ water\ permeable\ voids\ (V_p)\right] \times \gamma_w}$$

$$= \frac{W_s}{(V_s + V_i + V_p) \times \gamma_w}$$

Aggregates - Properties

Specific Gravity

$$\textbf{Bulk SSD Sp.Gr} = \frac{Dry\ weight}{[Total\ particle\ volume] \times \gamma_w} = \frac{W_s + W_p}{(V_s + V_i + V_p) \times \gamma_w}$$

$$\textbf{Apparent SSD Sp.Gr} = \frac{SSD\ weight}{[Volume\ not\ accessible\ to\ water] \times \gamma_w} = \frac{W_s + W_p}{(V_s + V_i) \times \gamma_w}$$

$$\textbf{Effective SSD Sp.Gr}\ (considered\ when\ aggregates\ are\ mixed\ with\ Asphalt\ binder)$$
$$= \frac{Dry\ weight}{[Volume\ not\ accessible\ to\ asphalt] \times \gamma_w} = \frac{W_s}{(V_s + V_c) \times \gamma_w},$$

$$where, \gamma_w = Unit\ weight\ of\ water,$$
$$V_c = Volume\ of\ voids\ not\ filled\ with\ Asphalt\ cement$$

Aggregates – Properties

Relationship between Bulk Unit Weight and Voids in aggregate

- The bulk unit weight of aggregate γb is determined as:

$$\gamma_b = \frac{W_s}{V_s}$$

- Where $W_s = Weight\ of\ aggregate\ and\ V_s = Volume\ of\ aggregate$
- If $SG_{sb} =$ $bulk\ dry\ specific\ gravity\ of\ aggregate, \%\ of\ voids\ between\ aggregates$ can be determined as follows:

$$\%V_s = \frac{\gamma_b}{G_{sb} \times \gamma_w} \times 100\%$$

$$\%Voids = 100 - \%V_s$$

Aggregates - Properties

Bulk Unit Weight - Example

- Coarse aggregate is placed in a rigid bucket and rodded with a tamping rod to determine its unit weight. The following data are obtained:
- Volume of Aggregate = 0.009438854m³,
- Weight of dry rodded coarse aggregate = 0.16636 kN
- Calculate the dry-rodded unit weight
- If the bulk dry specific gravity of the aggregate is 2.630, calculate the percent voids in the aggregate.

Solution Part a

$$\gamma_b = \frac{W_s}{V_s} = \frac{0.16636kN}{0.009438854m^3} = 17.625kN/m^3$$

Aggregates - Properties

Bulk Unit Weight - Example

- Coarse aggregate is placed in a rigid bucket and rodded with a tamping rod to determine its unit weight. The following data are obtained:
- Volume of Aggregate = 0.009438854m³,
- Weight of dry rodded coarse aggregate = 0.16636 kN
- Calculate the dry-rodded unit weight
- If the bulk dry specific gravity of the aggregate is 2.630, calculate the percent voids in the aggregate.

Solution Part b

$$\%V = 100 - \%V_s$$

$$\%V = \frac{\gamma_b}{G_{sb} \times \gamma_w} \times 100\%$$

$$\gamma_w = 9.807\ kN/m^3$$

$$\%V_s = \frac{17.625}{2.630 \times 9.807} \times 100 = 68.3\%$$

$$\%Voids = 100 - 68.3\% = 31.7\%$$

QUIZ 4:

Labs: Click on the hyperlinks to watch the videos

1. Fineness test of Cement Test
2. Soundness Test by Le-Chatelier Method
3. Determination of Specific Gravity of Cement
4. Aggregate Flakiness & Elongation Index Test
5. Aggregate Los Angeles Abrasion Value Test
6. Aggregate Crushing Value
7. Coarse Aggregate Specific Gravity

Thank You!!!