

CEMENT and CONCRETE TECHNOLOGY

Prepared by:

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2009/2010

Cement and Concrete Technology (ECIV 3341) Second Semester 2009/2010

Course Outline

Course Description: Mineral aggregates; properties and testing. Portland Cement; manufacturing, composition, hydration, properties and testing. Proportioning concrete Mixes. Mechanical properties and testing of hardened concrete. Masonry, manufacturing and testing. Manufacturing, properties, and testing of steel. Metals materials manufacturing and classification. Methods of testing and proportioning asphalt mixes. Classification and properties of wood and plastics.

Instructor: Eng. A. EL KOURD

Prerequisites ECIV 2204 Engineering Geology

Text Book: Concrete, by Sidney Mindess, S., Young, J. F., and Darwin, D., Prentice-Hall, Inc.

Englewood cliffs,

New Jersey, second Edition, 2003.

References:

Materials for Civil & Highway Engineering, by Kenneth N. Derucher and George Korfiatis, Prentic Hall, Englewood cliffs, New Jersey 07632, 1988.

Basic Construction Materials, by C. A. Herubin and T. W. Marotta, Reston publishing, Virginia, 1990. Properties of Concrete, by A. M. Niville and J. J. Brooks, Bitman, 1981.

Other available relevant references.

Course Aims: The main aims is to familiarize students with physical properties and mechanical behavior of various construction materials with main emphasis being placed on concrete. This includes detailed discussions of concrete constituents: cement, aggregates, water and admixtures. Relevant aspects related to fresh and hardened concrete, i.e. mixing, handling, casting, curing, standards, testing, strength, deformation, durability and quality control are also discussed. Other construction materials discussed in the course include timber, Metals and plastics. Special topics and new developments related to the materials used in the construction industry may be reviewed.

Course intended Learning Outcomes (ILOs):

Knowledge of cement origin, properties and types

Knowledge of aggregate properties and classification

Knowledge Fresh and harden concrete properties

Using concrete laboratory to find concrete properties

Course Conduct: Midterm Exam (35 points), Assignments & Presentations (15 points) and Final Exam (50 points).

Course Outline:

$\hfill\square$ Introduction: constituents, history, advantages, limitations and applications.
☐ Aggregates: physical and mechanical properties.
\Box Cement: raw materials, manufacture, composition and types, special cements, hydration, tests of cement, paste and mortar.
☐ Water: mixing and curing requirements, tests.
$\hfill \Box$ Admixtures: types, water reducing (superplasticizers), set-retarders, accelerators and air entraining agents.
☐ Fresh concrete: workability, segregation, bleeding and tests.
☐ Practical considerations: mixing, handling, casting, compaction, curing and removal of formworks.
\square Hardened Concrete: physical, chemical and engineering properties, tensile and compressive strengths, other strength, deformation, elasticity, shrinkage, creep destructive and non-destructive tests.
\square Mix design: influencing factors, various methods of mix proportioning and design of normal strength concrete including prescriptive, standard and designed mixes. \square Quality control: variation in strengths and compliance requirements.
☐ Metal: manufacture, physical and mechanical characteristics, and testing.

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<u>Course Conduct:</u> Midterm Exam (35 points), Assignments & Presentations (15 points), and Final Exam (50 points).

Course Outline:

- Introduction: constituents, history, advantages, limitations and applications (<u>lecture notes</u>) (one hour).
- \diamond Aggregates: physical and mechanical properties (<u>lecture 1, 2</u> and <u>3</u>).
- ❖ Cement: raw materials, manufacture, composition and types, special cements, hydration, tests of cement, paste and mortar (<u>lecture 1</u>, <u>2</u> and <u>3</u>) (5 hours).
- ❖ Water: mixing and curing requirements, tests (lecture notes) (one hour).
- Admixtures: types, water reducing (superplasticizers), set-retarders, accelerators and air entraining agents (<u>lecture 1</u>, <u>Lecture 2</u>, <u>Sika Admixtures</u>, (http://www.sikaconstruction.com/con/con-admixture_in_con-prod-category-hrwr.htm)).
- Fresh concrete: workability, segregation, bleeding and tests (lecture 1 and lecture 2).
- ❖ Practical considerations: mixing, handling, casting, compaction, curing and removal of formworks (<u>lecture1</u>, <u>2</u>, <u>supplementary lecture</u>).
- ❖ Hardened Concrete: physical, chemical and engineering properties, tensile and compressive strengths, other strengths, deformation, elasticity, shrinkage, creep destructive tests and non-destructive tests (lecture 1, lecture 2).
- ❖ Mix design: influencing factors, various methods of mix proportioning and design of normal strength concrete including prescriptive, standard and designed mixes (<u>Part 8-1</u>, <u>part 8-2</u>).
- Quality control: variation in strengths and compliance requirements.
- ❖ Metal: manufacture, physical and mechanical characteristics, and testing (Part 10-1).
- Timber: physical and mechanical characteristics, and testing.

Chapter 1: Introduction

Definition of Concrete

Concrete is a mixture of cement (11%), fine aggregates (26%), coarse aggregates (41%) and water (16%) and air (6%).

Cement → Powder

Cement + Water → Cement Paste

Cement Paste + Fine Aggregate (FA) → Mortar

Mortar + Coarse Aggregate (CA) → Concrete

Portland cement, water, sand, and coarse aggregate are proportioned and mixed to produce concrete suited to the particular job for which it is intended.

Definition of Cement

Portland cements are hydraulic cements, meaning they react and harden chemically with the addition of water. Cement contains limestone, clay, cement rock and iron ore blended and heated to 1200 to 1500 °C. The resulting product "clinker" is then ground to the consistency of powder. Gypsum is added to control setting time.

Definition of Fine Aggregate

Normally called sand, this component can be natural sand or crushed stone, and represents particles smaller than 3/8". Generally accounts for 30%-35% of the mixture.

Definition of Coarse Aggregate

May be either gravel or crushed stone. Makes up 40%-45% of the mixture, comprised of particles greater than 1/4".

Definition of Chemical Admixtures

Materials added to alter the properties of concrete including:

- Air entrainment
- Set accelerators
- Set retarders
- Water reducers

Air entraining admixtures add microscopic air bubbles to the concrete, enhancing its resistance to freeze/thaw cycles and makes the concrete easier to finish.

Set accelerators speed the set-time of the mixture, enabling finishing operations to begin sooner, useful during cold weather pours. Set retarders have the opposite effect, slowing the set and enabling delivery to distant sites and finishing during hot weather.

Water reducers are used to reduce the amount of water required to produce a given slump. They also provide a ball bearing effect, making the concrete easier to finish, and produce better cement hydration. By reducing the amount of water required, cement amounts can be reduced because concrete strength is directly related to the water/cement ratio.

Definition of Mineral Admixtures

Mineral admixtures include fly ash, hydrated lime, silica fume and ground blast furnace slag. Many of these materials have cement-like properties, augmenting the strength and density of the finished concrete. They generally improve the workability, density and long-term strength of concrete, at the expense of set time and early strengths.

Definition of Synthetic Fibres

These are thin polypropylene fibres used as secondary reinforcement. They help control shrinkage cracking and provide some impact resistance.

Definition of Grout

Grout is a mixture of cement, water and (most generally) fine aggregate. It is mixed to a pourable consistency and used to fill spaces within block walls, or other cavities. They generally contain large amounts of cement.

Definition of Flowable Fill

Flowable fill is a self-leveling, self-compacting backfill material. Can be produced in structural and excavatable (by hand or machine) forms, making it ideal for use around utilities that may need to be uncovered at a later date. When calculated against labor costs, flowable fill provides an economical alternative to granular backfill.

Definition of Yield

Yield is the volume of fresh concrete produced from known quantities of component materials, generally expressed in cubic yards or cubic meters.

Advantages of Concrete

 Concrete has many environmental advantages, including durability, longevity, heat storage capability, and chemical inertness.

- Ability to be Cast
- Fire resistant
- On-site fabrication
- Aesthetic properties.
- The raw materials used in cement production are widely available in great quantities.
- Needs little or no finish or final treatments.
- Chemically inert concrete doesn't require paint to achieve a given colour; natural -mineral pigments and colouring agents can be added at the mixing to provide a rainbow of options.
- Low maintenance.
- Can be **reused** or **recycled**.
- Concrete can be reused with bituminous asphalt as road base materials, can be recycled and reused by crushing into aggregates for new concrete or as fill material for road beds or site works.

Limitations of Concrete

- Low tensile strength
- Low ductility
- Volume instability

• Low strength-to-weight ratio

Progress in Concrete Technology

- Lightweight Concrete
- High-Strength Concrete
- High Workability or Flowing Concrete
- Shrinkage Compensating Concrete
- Fiber-Reinforced Concrete
- Concrete Containing polymers
- Heavyweight Concrete
- Mass Concrete
- Roller-Compacted Concrete

The History of Concrete

Cement has been around for at least 12 million years. When the earth itself was undergoing intense geologic changes natural cement was being created. It was this natural cement that humans first put to use. Eventually, they discovered how to make cement from other materials.

12,000,000 BC	Reactions between <u>limestone</u> and oil shale during spontaneous combustion occurred in Palestine to form a natural deposit of <u>cement</u> compounds. The deposits were characterized by the geologists in the 1960's and 70's.
3000 BC Egyptians	Used mud mixed with straw to bind dried bricks. They also used gypsum mortars and mortars of lime in the pyramids.
Chinese	Used cementitious materials to hold bamboo together in their boats and in the Great Wall.
800 BC Greeks, Crete & Cyprus	Used lime mortars which were much harder than later Roman mortars.
300 BC Babylonians & As Syrians	Used bitumen to bind stones and bricks.
1200 - 1500 The Middle Ages	The quality of cementing materials deteriorated. The use of burning lime and <u>pozzolan</u> (admixture) was lost, but reintroduced in the 1300's.
1822	James Frost of England prepared artificial hydraulic lime like Vicat's and called it British Cement.
1824	Joseph Aspdin of England invented <u>portland cement</u> by burning finely ground chalk with finely divided clay in a lime <u>kiln</u> until carbon dioxide was driven off. The sintered product was then ground and he called it portland cement named after the high quality building stones quarried at Portland, England.
1828	I. K. Brunel is credited with the first engineering application of portland cement, which was used to fill a breach in the Thames Tunnel.
1830	The first production of lime and hydraulic cement took place in Canada.
1836	The first systematic tests of tensile and compressive strength took place in Germany.
1845	Isaac Johnson claims to have burned the raw materials of portland cement to clinkering temperatures.
1849	Pettenkofer & Fuches performed the first accurate chemical analysis of portland cement.

1860	The beginning of the era of portland cements of modern composition.		
1886	The first rotary kiln was introduced in England to replace the vertical shaft kilns.		
1889	The first concrete reinforced bridge is built.		
1890	The addition of gypsum when grinding clinker to act as a <u>retardant</u> to the <u>setting</u> of concrete was introduced in the USA. Vertical shaft kilns were replaced with rotary kilns and ball mills were used for grinding cement.		
1891	George Bartholomew placed the first concrete street in the USA in Bellefontaine, OH. It still exists today!		
1900	Basic cement tests were standardized.		
1930	Air entraining agents were introduced to improve concrete's resistance to freeze/thaw damage.		
1967	First concrete domed sport structure, the Assembly Hall, was constructed at The University of Illinois, at Urbana-Champaign.		
1970's	Fiber reinforcement in concrete was introduced.		
1980's	Superplasticizers were introduced as admixtures.		
1985	Silica fume was introduced as a pozzolanic additive. The "highest strength" concrete was used in building the Union Plaza constructed in Seattle, Washington.		

Chapter 2: Portland Cement

Cement is a pulverized material that develops binding forces due to a reaction with water.

- Hydraulic Cement → Stable under water
- Nonhydraulic Cement → Products of hydration are not resistant to water (i.e. limestone)

Hydraulic cements

Cements that harden by reaction with water and form a water-resistant product.

Portland Cement (P.C.)

Portland cement is a hydraulic cement capable of setting, hardening and remains stable under water. It is composed of calcium silicates and some amount of gypsum.

Blended Portland Cements

Blended cement, as defined in ASTM C 595, is a mixture of portland cement and blast furnace slag (BFS) or a "mixture of portland cement and a pozzolan (most commonly fly ash)."

The use of blended cements in concrete reduces mixing water and bleeding, improves finishability and workability, enhances sulfate resistance, inhibits the alkali-aggregate reaction, and lessens heat evolution during hydration, thus moderating the chances for thermal cracking on cooling.

Modified Portland Cement (Expansive Cement)

Expansive cement, as well as expansive components, is a cement containing hydraulic calcium silicates (such as those characteristic of portland cement) that, upon being mixed with water, forms a paste, that during the early hydrating period occurring after setting, increases in volume significantly more than does portland cement paste.

Expansive cement is used to compensate for volume decrease due to shrinkage and to induce tensile stress in reinforcement.

Expansive cement concrete used to minimize cracking caused by drying shrinkage in concrete slabs, pavements, and structures is termed shrinkage-compensating concrete.

Self-stressing concrete is another expansive cement concrete in which the expansion, if restrained, will induce a compressive stress high enough to result in a significant residual compression in the concrete after drying shrinkage has occurred.

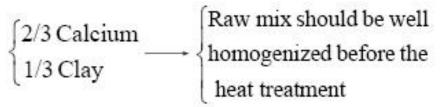
Manufacturing of Portland Cement

 Calcium silicates are the primary constituents of portland cement.

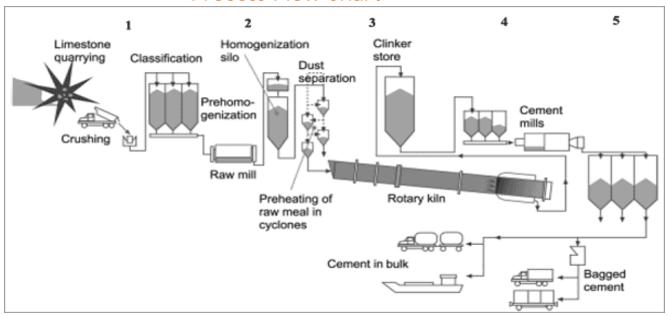
• Raw material for P.C. is Calcium & Silica

Calcium: Limestone, chalk, etc (CaO+CO2)

Silica: Clays and shales (SiO2+Al2O3+Fe2O3+H2O)



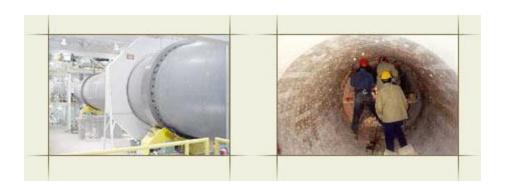
Process Flow Chart



Cement Making Process









Raw Mill Feed

Manufacturing Process



Kiln Line Overview

Manufacturing Process

1. Crushing and Proportioning

Limestone rock is the principal raw material, the first step after quarrying in the processes is the primary crushing. Mountains of rock are fed through crushers capable of handling pieces as large as an oil drum. The first crushing reduces the rock to a maximum size of about 15 cm (6 po). The rock then goes to secondary crushers or hammer mills for reduction to about 7.5 cm or smaller.

2. Raw milling & Blending

The next step in the process is to grind the above particles to a size of 90 microns or less which is done in a raw mill, a closed circuit ball mill equipped with high efficiency separator. After achieving the 90 microns size the fine grinded material also known as raw meal is sent to the continuous blending silos (CFC) for homogenization & extracted by means of load cell hopper for the next step which is feeding to the kiln pre heaters.

3. Pyro processing

The raw material is heated to exceeding 1,450 °C (2,700 degrees F) in huge cylindrical steel rotary kilns lined with special firebrick. Kilns are frequently as much as 3.7 M (12 pi) in diameter, large enough to accommodate an automobile and longer in many instances than the height of a 40-story building. Kilns are mounted with the axis inclined slightly from the horizontal. The finely ground raw material or the slurry is fed into the higher end. At the lower end is a roaring blast of flame, produced by precisely controlled burning of powdered coal, oil or gas under forced draft.

4. Burning and cooling

As the material moves through the kiln, certain elements are driven off in the form of gases. The remaining elements unite to form a new substance with new physical and chemical characteristics. The new substance, called clinker, is formed in pieces about the size of marbles.

Clinker is discharged red-hot from the lower end of the kiln and generally is brought down to handling temperature in various types of coolers. The heated air from the coolers is returned to the kilns, a process that saves fuel and increases burning efficiency.

5. Cement milling, Storage & Packing

Portland cement, the basic ingredient of concrete, is a closely controlled chemical combination of calcium, silicon, aluminum, iron and small amounts of other ingredients to which gypsum is added in the final grinding process to regulate the setting time of the concrete. Lime and silica make up about 85% of the mass. Common among the materials used in its manufacture are limestone, shells, and chalk or marl combined with shale, clay, slate or blast furnace slag, silica sand, and iron ore. The above mixture

Cement Chemistry

In cement chemistry, the individual oxides and clincker compounds are expressed by their abbreviations

Short Hand Notation

- C (CaO, calcium oxide)
- A (Al2O3, alumina)
- S (SiO2, silica)
- S (SO3, sulfate)
- H (H20, water)

Reactive Compounds

- C3S (tricalcium silicate)
- C2S (dicalcium silicate)
- C3A (tricalcium aluminate)
- CSH2 (gypsm)
- C4AF (tetra-calcium alumino ferrite)

Compounds of Portland Cement

```
 C<sub>3</sub>S 3CaO . SiO<sub>2</sub>
```

$$C_3S = Tricalcium Silicate$$

$$C_2S = Dicalcium Silicate$$

$$C_2S = Dicalcium Silicate$$

 $C_3A = Tricalcium aluminate$

 $C_4AF = Tetracacium aluminate ferrite$

Cement Chemistry

Hydration Reactions

■
$$2C_3A + C_6AS_3H_{32} + 4H \rightarrow 3C_4A\overline{S}H_{12}$$

Other Compounds

- Magnesium Oxide, MgO
- Calcium Oxide, Lime, CaO

• Alkali, Na20, K20

equivalent Na2O=(Na2O+0.46 K2O) limited to about 1-2%

Chapter 2: Portland Cement (cont.)

Cement Chemistry

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Cement Chemistry

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equivalent Na2O=(Na2O+0.46 K2O) limited to about 1-2%

Types of Portland Cement

ASTM C 150, Standard Specifications for Portland Cement

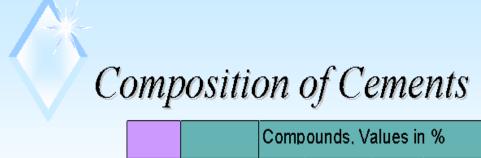
Type I: General purpose. For use when the special properties specified for any other types are not required.

Type II: For general use, more specially when moderate sulphate resistance or moderate heat of hydration is desired.

Type III: For use when high early strength is desired. (limit the C3A content of the cement to maximum 15%)

Type IV: For use when low heat of hydration is desired.

Type V: For use when high sulfate resistance is desired. (Maximum limit of 5% on C3A)



		Comp	Compounds, Values in %			
Type	Blaine Fineness m²/Kq	C₁S	C₂S	C₃A	C₄AF	
I .	369	54	18	10	8	
II .	377	55	19	6	11	
III	548	55	17	9	8	
IV	340	42	32	4	15	
V	373	54	22	4	13	
White		33	46	15	2	

^{*} Portland Cement Past and Present Characteristics, PCA, Concrete Technology Today, Vol 17, Number 2, July 1996

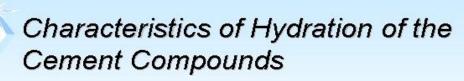
Comparison of the Characteristics of the Four Main Compounds in Portland Cement

	C ₃ S	C_2S	C₃A	C_4AF
Rate of hydration	Moderate	Slow	Fast	Moderate
Early Strength	High	Low	Low	Low
Ultimate Strength	High	High	Low	Low
Heat of Hydration	Medium	Low	High	Medium
Typical (cal/g)	120	60	320	100

HEAT OF HYDRATION

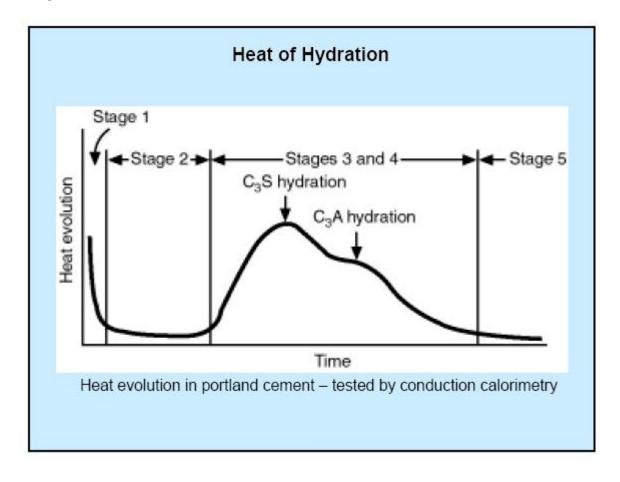
Heat of hydration is the heat generated when cement and water react. The amount of heat generated is dependent chiefly upon the chemical composition of the cement, with C3A and C3S being the compounds primarily responsible for high heat evolution.

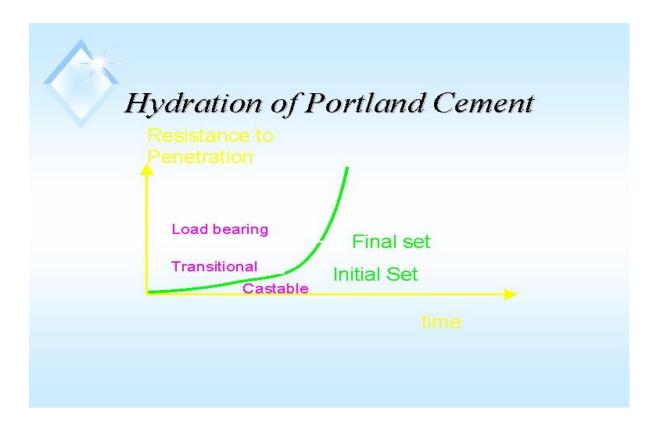
Characteristics of Hydration of the Cement Compounds



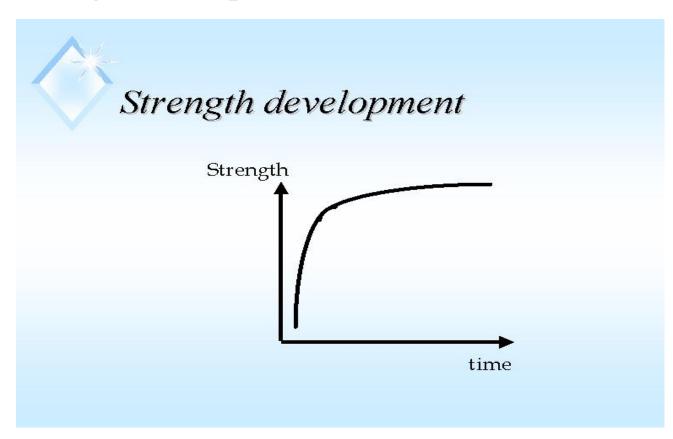
Compounds	Reaction Rate	Amount of Liberated	Strength	Heat Liberation
C3S C2S	Moderate		High	High
C2S	Slow	Low	Low initially, high later	Low
C3A + CSH2	Fast	Very high	Low	Very high
C4AF+CSH2	Moderate	Moderate	Low	Moderate

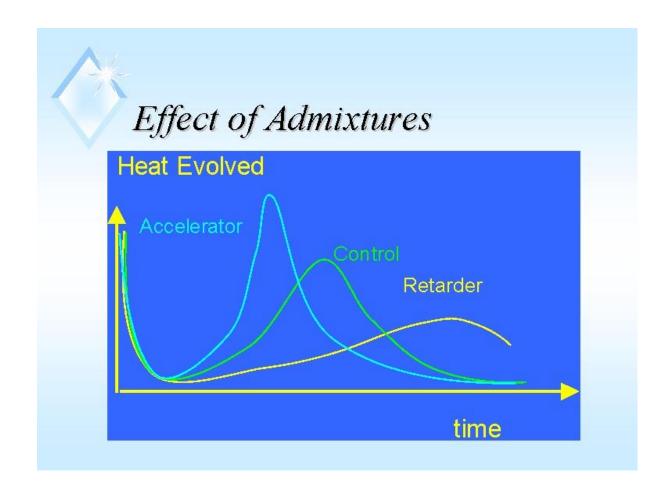
Hydration of Portland Cement





Strength development





Pozzolan

An inert silicious material which, in the presence of water, will combine with lime to produce a cementitious matter with excellent structural properties.

Advantages of Pozzolans

- Improved Workability
- Economy
- Reduced Alkali-aggregate Reaction
- Increased Sulphate Resistance

Chapter 2: Portland Cement (cont.)

Tests on Portland Cement

Composition

Chemical Name	Chemical Formula	Shorthand <u>Notation</u>	Mass <u>(%)</u>
Tricalcium silicate	3CaO•SiO ₂	C₃S	50 - 70
Dicalcium silicate	2CaO• SiO ₂	C₂S	15 - 30
Tricalcium aluminate	3CaO•Al ₂ O ₃	C ₃ A	5 - 10
Tetracalcium aluminoferrite	4CaO•Al ₂ O ₃ •Fe ₂ O ₃	C₄AF	5 - 15
Calcium sulfate dihydrate	CaSO₄•2H₂O	CSH₂	~ 5

The relative quantities of each of these phases affects:

- setting time
- rate of strength development
- overall strength
- durability
- color

It is important, then, to know the composition of the cement.

Chemical Properties of Portland Cement

Chemical analysis

• Compound composition

Chemical limits

Chemical Analysis

SiO ₂	Silicon dioxide
Al ₂ O ₃	Aluminum oxide
Fe ₂ O ₃	Ferric oxide
CaO	Calcium oxide
MgO	Magnesium oxide
SO ₃	Sulfur trioxide
LOI	Loss on ignition
Na ₂ O	Sodium oxide
K ₂ O	Potassium oxide
TiO ₂	Titanium dioxide
P ₂ O ₅	Phosphorus pentoxide
ZnO	Zinc oxide
Mn ₂ O ₃	Manganic oxide
Sulfide su	ılfur

ASTM C 114 Standard Test Methods for Chemical Analysis of Hydraulic Cement

Major components

Separate determinations

- Insoluble residue
- · Free calcium oxide
- CO₂ (carbon dioxide)
- Water-soluble alkali
- Chloroform soluble organic substances

Minor components

ASTM C114							
Oxide	Analysis	_	Oxide	Shorth	and_	Common Name	
Oxide	%		CaO	С		lime	
SiO ₂	20.6	1	SiO ₂	S		silica	
Al ₂ O ₃	5.07	1	Al_2O_3	А		alumina	
Fe ₂ O ₃	2.90	90 – 95%	Fe ₂ O ₃	F		ferric oxide	
CaO	63.9		MgO	М		magnesia	
MgO	1.53				,		
K₂O	0.73		K ₂ O	K	}	alkalis	
Na ₂ O	0.15		Na₂O	N	J		
SO₃	2.53		SO ₃	s		sulfate	
LOI	1.58		CO ₂	C		carbonate	
+ other trac	e elements		H ₂ O	Н		water	

Compound Composition

Bogue Composition

 $C_3S = 4.07C - 7.60S - 6.72A - 1.43F - 2.85\overline{S}$

 $C_2S = 2.87S - 0.75C_3S$

 $C_3A = 2.65A - 1.69F$

 $C_4AF = 3.04F$

(Only valid when A/F ≥ 0.64)

Bogue Composition: Example

Oxide Analysis

Oxide	%
SiO ₂	20.6
Al ₂ O ₃	5.07
Fe ₂ O ₃	2.90
CaO	63.9
MgO	1.53
K₂O	0.73
Na ₂ O	0.15
SO ₃	2.53
LOI	1.58

Calculated Phase Composition

$$C_3$$
S = 4.07(63.9) - 7.60(20.6) - 6.72(5.07)
- 1.43(2.90) - 2.85(2.53) = **58.1**

$$C_2S = 2.87(20.6) - 0.754(58.1) = 15.6$$

$$C_3A = 2.65(5.07) - 1.69(F 2.90) = 8.5$$

$$C_4AF = 3.04(2.90) = 8.8$$

Bogue Potential Composition:

C ₃ S	58%
C ₂ S	16%
C ₃ A	9%
C₄AF	9%

Physical Properties of Portland Cement

- Fineness
- Soundness
- Consistency
- Setting time
- False set and flash set
- Compressive strength
- Heat of hydration
- Loss on ignition
- Density
- Bulk density
- Sulfate expansion

Fineness

Fineness of cement is also important; it affects:

- rate of hydration
- rate of setting
- · rate of hardening
- durability (ASR)
- rate of carbonation during storage
- cost
- rate of gypsum addition
- bleeding

However, later strength is not directly affected.

Cement Fineness

Requirements for Type I, II, IV & V (No requirements for Type III)

Minimum, m²/kg ASTM C 150 & 280 160

Maximum, m²/kg AASHTO M 85 400 220

Typical values, m²/kg 350-380 Type I

450-600 Type III

No limits for blended cement (ASTM C 595) or hydraulic cements (ASTM C 1157) but values must be reported on mill test reports

Soundness

Soundness - ability of hardened paste to maintain volume after setting

Unsoundness (abnormal expansion) caused by hard-burned CaO or MgO

$$\begin{aligned} & CaO + H_2O \rightarrow Ca(OH)_2 \\ & MgO + H_2O \rightarrow Mg(OH)_2 \end{aligned}$$

ASTM C 151 Standard Test Method for Autoclave Expansion of Portland Cement

Expansion for all portland, ≤ 0.80% blended & hydraulic cements



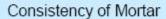


Consistency



Consistency of Cement Paste

- Penetration of 10 ± 1 mm of Vicat plunger
- ASTM C 187 Standard Test Method for Normal Consistency of Hydraulic Cement



- Flow table
- ASTM C 1437 Standard Test Method for Flow of Hydraulic Mortar





Setting Time

Initial Set Time from moment water is added until the paste

ceases to be fluid and plastic

Final Set Time from moment water is added for the paste to

acquire a certain degree of hardness





Setting Time: Standard Test



Vicat Needle

- ASTM C 191 Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle
- Initial set occurs when needle penetrates
 after 30s 25 mm (1 inch) into paste
- Final set occurs when there is no visible penetration

Setting Time: Field Measurements



- Concrete penetrometer, measures resistance to penetration in sieved mortar samples
- Pocket penetrometers



Setting Time: Standard Test

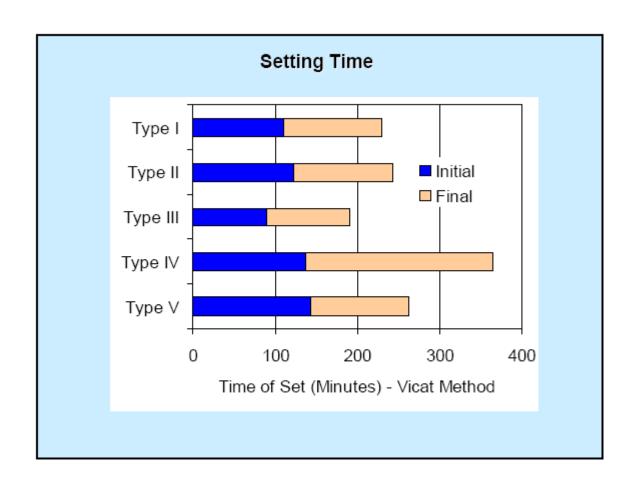


Gillmore Needles

- ASTM C 266 Standard Test
 Method for Time of Setting of
 Hydraulic-Cement Paste by
 Gillmore Needles
- Setting determined as time when paste resists indentation by needles

Setting Time

	Vicat Needle	Gillmore Needles
ASTM C 150 Portland Cement		
Initial Set, not less than (h:min)	0:45	1:00
Final Set, not more than (h:min)	6:15	10:00
ASTM C 595 Blended Cement		
Initial Set, not less than (h:min)	0:45	
Final Set, not more than (h:min)	7:00	
ASTM C 1157 Hydraulic Cement		
Initial Set, not less than (h:min)	0:45	
Final Set, not more than (h:min)	7:00	



False Set and Flash Set "Early Stiffening"

False Set

- Loss of plasticity shortly after mixing little heat
- Due to hemihydrate (plaster) in cement hydrating to gypsum
- Workability restored by additional mixing

False Set and Flash Set

"Early Stiffening"

False Set

- Loss of plasticity shortly after mixing little heat
- Due to hemihydrate (Plaster) in cement hydrating to Gypsum
- · Workability restored by additional mixing

Flash Set

- Rapid & early loss of workability significant heat
- Due to rapid reaction of aluminates when insufficient sulfate present
- · Workability cannot be restored

Compressive Strength

ASTM C 109 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars.

- 50-mm (2-inch) mortar cubes
- Sand:Cement = 2.75:1
- Water/Cement = 0.485 for portland cement (0.460 for air-entraining portland cement)
- Sufficient water for flow 110 ± 5 for blended (ASTM C 595) and hydraulic (ASTM C 1157) cements



Compressive Strength

ASTM C 150 Standard Specification for Portland Cement

Minimum Strength Requirements, MPa (psi)

Age	Cement Type				
	I	II	III	IV	V
1 day	-	1	12.0 (1740)	-	-
3 days	12.0 (1740)	10.0 (1450)	24.0 (3480)	-	8.0 (1160)
7 days	19.0 (2760)	17.0 (2470)	-	7.0 (1020)	15.0 (2180)
28 days	-	-	-	17.0 (2470)	21.0 (3050)

Lower strengths permitted for air-entraining cements (Types IA, IIA & IIIA) and when heat of hydration option is specified for Type II cement

Loss on Ignition

ASTM C 114 Standard Test Methods for Chemical Analysis of Hydraulic Cement

- Loss on ignition LOI
- Sample ignited at 900 to 1000°C (1650 to 1830°F)
- High LOI indicates prehydration and/or carbonation
- Improper or prolonged storage (transportation)

ASTM C 150 Portland Cement

ASTM C 595 Blended Cement

ASTM C 1157 Hydraulic Cement

LOI ≤ 3.0% (2.5% for Type IV)

 $LOI \le 3.0 - 5.0\%$

No limit - must be reported

Density



Le Chatelier flask - ASTM C 188 Standard Test Method for Density of Hydraulic Cement

- Range= 3100 to 3250 kg/m³
- Average = 3150 kg/m³ (196 lb/ft³)
- · Not indicator of quality
- Used for mixture proportioning calculations

Relative density (specific gravity) = 3.15



Helium pycnometer

Bulk Density



Bulk density of cement varies between

830 kg/m³ (52 lb/ft³)

and

1650 kg/m3 (103 lb/ft3).

Sulfate Expansion

ASTM C 452 Standard Test Method for Potential Expansion of Portland-Cement Mortars Exposed to Sulfate

- Gypsum added to cement to yield 7.0% SO₃ (by mass of cement + gypsum)
- · Mortar bars stored in water
- Length change monitored periodically
- · Only applicable to portland cements

ASTM C 150 Portland Cement

Optional requirement for Type V Sulfate-Resisting Portland Cement

Expansion ≤ 0.040% at 14 days Limits for C₃A, C₄AF + 2C₃A, SiO₂ & Fe₂O₃ not required

Chapter 3: Mixing Water for Concrete

The requirements of mixing water for concrete

Almost any natural water that is drinkable and has no pronounced taste or odor can be used as mixing water for making concrete.

Drinkable Water is good for making concrete

• Some waters that are not fit for drinking may be suitable for concrete making provided that they satisfy the acceptance criteria laid by ASTM C 94 (Tables 3.1)

Table 3.1 Acceptance Criteria for Questionable Water Supplies (ASTM C 94)

	Limits	Test method
Compressive Strength, minimum percentage of control at 7 days	90	ASTM C 109 or T 106
l Time of set deviation	From 1:00 earlier to 1:30 later	ASTM C 191 or T 131

Excessive impurities in mixing water affect setting time and concrete strength and also cause efflorescence (deposits of white salts on the surface of concrete), staining, corrosion of reinforcement, volume changes, and reduced durability

Impurity	Effects
1. Alkali carbonate and bicarbonate	Acceleration or retardation of setting time. Reduction in strength
2. Chloride	Corrosion of steel in concrete
3. Sulfate	Expansive reactions and deterioration of concrete. Mild effect on corrosion of steel in concrete
4. Iron salts	Reduction in strength
5. Miscellaneous inorganic salts (zinc, copper, lead, etc)	Reduction in strength and large variations in setting time
6. Organic substances	Reduction in strength and large variations in setting time
7. Sugar	Severely retards the setting of cement
8. Silt or suspended particles	Reduction in strength
9. Oils	Reduction in strength

Use of Questionable Waters as Mixing Water

Sea Water

- Seawater containing up to 35,000 ppm of dissolved salts is generally suitable as mixing water for plain concrete
- Seawater is not suitable for use in making steel reinforced concrete and prestressed concrete due to high risk of steel corrosion

Acid Waters

- Acid waters may be accepted as mixing water on the basis of their pH values.
- Use of acid waters with pH values less than 3.0 should be avoided.
- Organic acids, such as tannic acid can have significant effect on strength at higher concentrations.

Alkaline Waters

 Waters with sodium hydroxide concentrations up to 0.5 % and potassium hydroxide in concentrations up to 1.2 % by weight of cement has no significant effect on strength.

- The possibility for increased alkali-aggregate reactivity should be considered before using the alkaline water as mixing water.
- Tannic acid can have significant effect on strength at higher concentrations.

Wash Waters

• Wash waters may be reused as mixing water in concrete if they satisfy the limits in Tables 3.1 and 3.2

Table 3.2 Chemical Limits for Wash Water used as Mixing water (ASTM C 94)

Total solids	50,000	AASHTO T 26
Alkalies, as (Na2O+0.658 K2O)	600	
Sulfate, SO4	3,000	ASTM D 516
Other reinforced concrete	1000	
Prestressed concrete or concrete in bridge decks	500	
Chloride, as Cl		ASTM D 512
Chemical or type of construction	Maximum concentration, ppm	Test Method

Industrial Wastewaters

- Industrial wastewaters may be used as mixing water in concrete as long as they only cause a very small reduction in compressive strength, generally not greater than 10 % to 15 %.
- Wastewaters from paint factories, coke plants, and chemical and galvanizing plants may contain harmful impurities. Thus such wastewaters should not be used as mixing water without testing.

Sanitary Sewage

• The sanitary sewage may be safely used as mixing water after treatment or dilution of the organic matter.

Chapter 5: Aggregates For Concrete

Aggregate is a rock like material which used in many civil engineering and construction applications including:

- Portland cement concrete
- Asphalt concrete
- Base materials for roads
- Ballast for railroads
- Foundations
- Plaster, mortar, grout, filter materials, etc.

Aggregates Types

GRAVEL

- Naturally occurring, water born pieces of rock, in buried or current stream beds.
- Normally rounded with smooth surfaces, other properties dependent on parent rock.
- Crushed gravel is larger gravel particles that have been reduced in size by a crusher.
- May be washed to remove undesirable material.

 May be screened to divide into desired size groupings.

SANDS

Naturally occurring, water or wind born pieces of rock in buried or current stream beds or dunes.

Often rounded with smooth surfaces, other properties dependent on parent rock.

May be washed to remove undesirable material.

May be screened to divide into desired size groupings.

Classification of Natural Aggregates

Rocks are classified according to origin into three major groups:

- 1. Natural Mineral Aggregates Sand, gravel, and crushed rock derived from natural sources.

 - (b) Sedimentary Rocks Stratified rocks (cost effective— near the surface; about 80% of aggregates; Natural sand and gravel) Limestone, sandstone → Excellent to poor

(c) Metamorphic Rocks - Igneous or sedimentary rocks that have changed their original texture, crystal structure, or mineralogy composition due to physical

and chemical conditions below the earth's surface.
Marble, schist, slate → Excellent to poor

2. Synthetic Aggregates

- Thermally processed materials, i.e. expanded clays and shale.
- Aggregates made from industrial by-products,
 i.e. blast-furnace slag & fly ash.

3. Recycled Aggregates

- Made from municipal wastes and recycled concrete from demolished buildings and pavements.
- Problems: Cost of crushing, grading, dust control, and separation of undesirable constituents.

Normal Weight

Gravels, Sands, Normal Crushed Stone, Bulk Specific Gravity - 2.4 to 2.9, Bulk Density (of Bulk Unit Weight) - 1520 to 1680 kg/m3, Most commonly used.

Light Weight

Manufactured or Natural, Bulk Density Less than 1120 kg/m3. Most commonly used in lightweight concrete, many must be screened to get the

desired size distribution, and some must be crushed.

Heavy Weight

Aggregates weighing more than 2080 Kg/m3 are called heavyweight.

Concrete Aggregates

- It is economical to put as much aggregate into a concrete mix as possible while not sacrificing other properties.
- However, Economy is not the only reason for using aggregate; it also confers greater volume stability and better durability than cement paste alone.
- Concrete Aggregates Influences dimensional stability, elastic modulus, durability, workability, and cost of concrete.

Classification

```
Coarse Aggregate (CA)
```

Size: 4.75 mm (3/16 in.) to 50 mm (2 in.) (retained on No. 4 sieve)

Fine Aggregate (FA)

Size: <4.75 mm; >75 μ m (0.003 in.) (retained on No. 200 sieve)

Mass concrete may contain up to 150-mm (\approx 6 in.)

coarse aggregate.

Aggregate Characteristics Affecting Concrete Behavior

1. Characteristics controlled by porosity

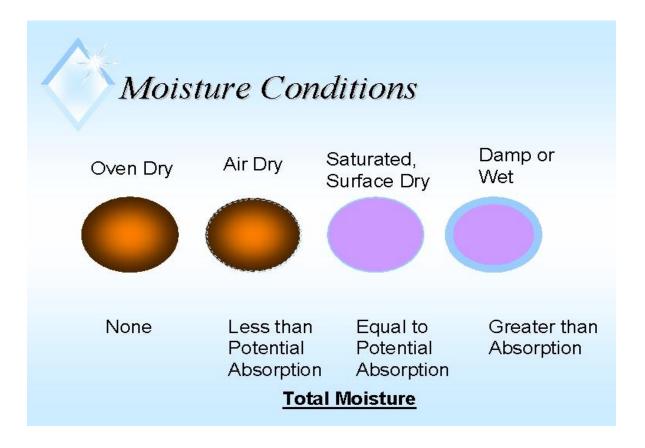
A. Density

- I) Apparent specific gravity: Density of the material including the internal pores.
- II) Bulk density (dry-rodded unit weight) weight of aggregate that would fill a unit volume; affects the following concrete behavior: mix design, workability, and unit weight.

Free Moisture and Absorption of Aggregates

- The moisture content and absorption of aggregates are important in calculating the proportions of concrete mixes since any excess water in the aggregates will be incorporated in the cement paste and give it a higher water/cement ratio than expected.
- All moisture conditions are expressed in terms of oven dry unit weight.

B. Absorption and Surface Moisture

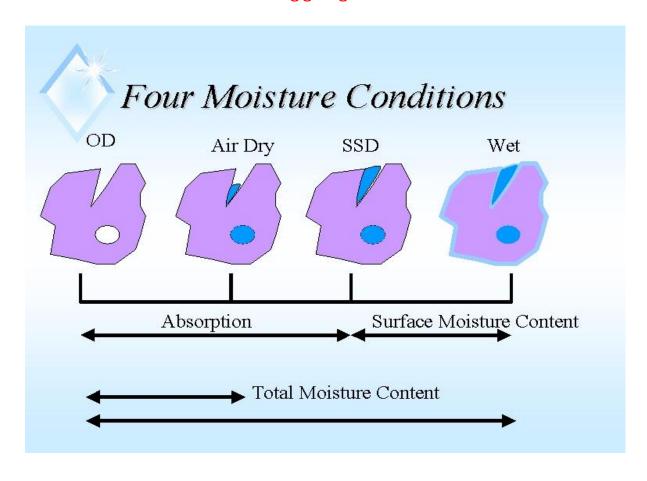


Moisture conditions of aggregates:

- Oven-dry Condition: All free moisture, whether external surface moisture or internal moisture, driven off by heat.
- Air dry: No surface moisture, but some internal moisture remains.
- Saturated-surface dry condition (SSD):
 Aggregates are said to be SSD when their moisture
 states are such that during mixing they will neither
 absorb any of the mixing water added; nor will they
 contribute any of their contained water to the mix.
 Note that aggregates in SSD condition may possess
 "bound water" (water held by physical chemical
 bonds at the surface) on their surfaces since this
 water cannot be easily removed from the aggregate.

• Damp or Wet condition: Aggregate containing moisture in excess of the SSD condition.

The Free Water, which will become part of the mixing water, is in excess of the SSD condition of the aggregate.



Definitions of Moisture Terms

- Absorption Amount of water needed to bring the aggregate to a saturated surface dry condition. Represents the internal pore volume.
 - ♦ Absorption % = $(W_{SSD} W_{OD})/W_{OD} * 100$
- ◆ Total Moisture Content total amount of water present on the internal and external surfaces of aggregates
 - $\bullet \text{ TMC } \% = (W W_{OD})/W_{OD}$
- ◆ Surface Moisture Content-total amount of water present on the external surfaces of aggregates. A negative SMC means that aggregate is Air Dry
 - ◆ SMC = TMC ABS



Moisture conditions

- ◆ Absorption, ABS
 - ◆ property of aggregate
 - $\bullet (W_{ssd} W_{od}) / W_{od} x 100$
- ◆ Total Moisture Content, TMS
 - depends on the field conditions
 - ♦ (W_{wet} W_{od})/ W_{od} x100
- ◆ if TMS > ABS, surface water present
- ◆ if TMS < ABS, aggregate is air dry

 Absorption and surface moisture affects the following concrete behaviors: mix-design, strength (pages 122, 123, 124 and 125 of the text book).

Note: Study well pages 132, 133 and 134 in the text book for more details.

Chapter 5: Aggregates For Concrete (cont.)

Aggregate Characteristics Affecting Concrete Behaviour (cont.)

2. Characteristics dependent on prior exposure and processing factors

A. Aggregate Size distribution

Aggregate size Distribution

- ♦ Sieve Analysis
- ◆ maximum size
- ◆ nominal maximum size
- ◆ Significance of Grading
 - ◆ Economy
 - ◆ Consistency
 - ◆ Strength
 - ◆ Shrinkage
 - ◆ Finishability

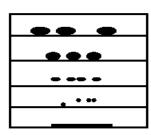
Grading

- ◆ Refers to distribution of particle sizes
- ◆ Sieve Analysis

We are interested in:

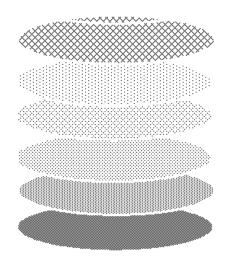
- ◆ 1) Size largest particle present
- ◆ 2) Size Distribution





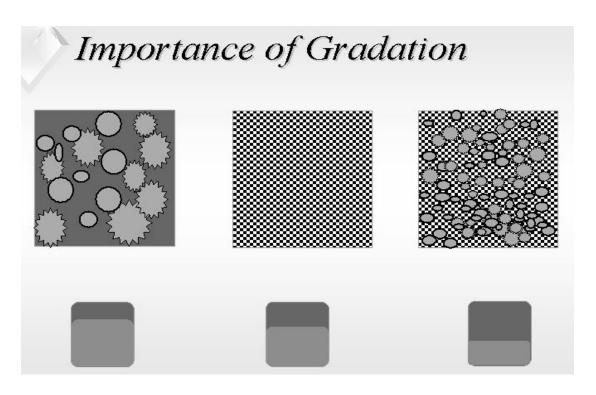
Sieve Analysis

- sieve sizes for coarse aggregates
- ◆ 1.5",1",3/4",1/2",3/8", No.4, (0.187in)
- ◆ Coarse aggregate if less than 10% passes No.4 Sieve

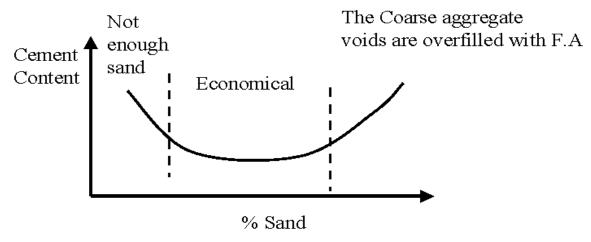


Sieve analysis and Fineness modulus of Sand

Sieve Size	% retained between sieves	Cum. % passing, by mass	Cum. % retained by mass
5 mm	2	98	2
2.5 mm	113	85	15
1.25 mm	20	65	35
630 microns	20	45	55
315 microns	24	21	79
160 microns	18	3	97
Fineness Mo	odulus= 280	3/100=2.83	283



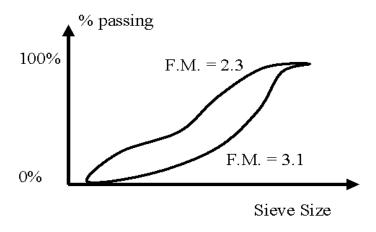
Significance of Grading



Fineness Modulus (FM)

- 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.

Maximum Aggregate Size (MSA)

Definition (ASTM): It is the smallest sieve opening through which the entire sample passes (or in practice only 5% retained on this sieve.

 MSA < 1/5 of the narrowest dimension of the form in which concrete is to be placed. Also: MSA < 3/4 of the minimum clear distance between the re-bars

<u>Nominal Max Size</u> – the largest size particle present significantly to affect concrete properties.

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).

B. Shape and Surface Texture

Rough-textured and elongated particles require more cement paste to produce workable concrete mixtures, thus increasing the cost.

Shape:

- Round loosing edges and corners.
- Angular well defined edges and corners.
- Elongated- when length is considerably larger than the other two dimensions.
- Flaky or flat- when thickness is small relative to two other dimensions.

Surface Texture

The degree to which the aggregate surface is smooth or rough- (based on visual judgement).

 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.

What is Gap grading? How it is important for concrete? Where you can use it? Get more details from your text book.

What is meant by Grading curves?

C. Soundness

Aggregate is considered unsound when volume changes in the aggregate induced by weather, such as alternate cycles of wetting and drying or freezing and thawing, result in concrete deterioration.

It Depends on: porosity and contaminants.

Pumice- (10% absorption) - no problem with freezing and thawing.

Limestone - breaks: use smaller aggregates (critical size) (critical aggregate size: size below which high internal stresses capable of cracking the particle will not occur)

Durability of Aggregates

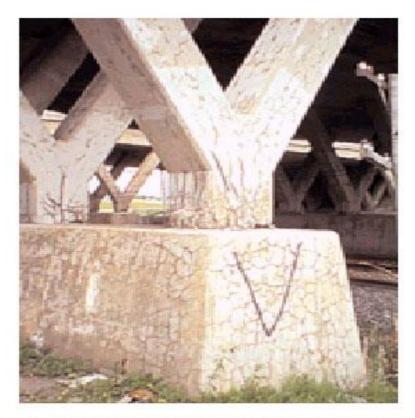
- Any lack of durability of the aggregate will have disastrous consequences for the concrete.
- Durability can be divided into physical and chemical causes.
- Physical durability exposure to freezing and thawing, wetting and drying, physical wear.
- Chemical durability –various forms of cement aggregate reactions (alkali –silica attack).

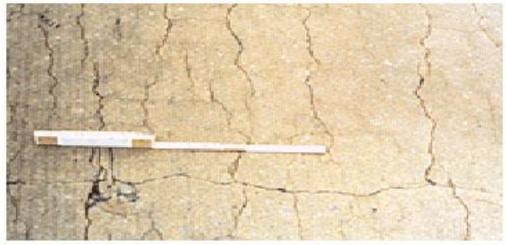
Physical Durability

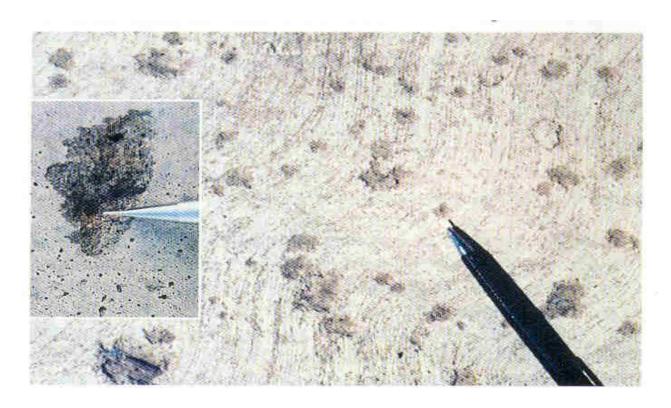
- **♣** Soundness: if volume changes accompanied with environmental changes lead to the deterioration of concrete –unsoundness.
- **♣** Volume changes: alternate freezing and thawing, repeated wetting and drying –internal stresses volume increase.
- **Wear resistance: resistance to surface abrasion** and wear.

Chemical Durability

♣ It results from a reaction between reactive silica in aggregates and alkalis compounds contained in the cement –alkali-aggregate reaction.







Popouts

Tests on Aggregates

Bulk Density (ASTM C 29)

- Defined as the weight of the aggregate particles that would fill a unit volume. The term *bulk* is used since the volume is occupied by both the aggregates and voids. The typical bulk density used in making normal concrete ranges from 1200 to 1750 kg/m³.
- The void contents range between 30% to 45% for coarse aggregate and 40% to 50% for fine aggregate. Void content increases with angularity and decreases with well graded aggregate.

Relative Density (Specific Gravity)

- The relative density of an aggregate (ASTM C 127 and C 128) is defined is the ratio of its mass to the mass of an equal absolute of water. It is used in certain computations for mixture proportioning and control. Most natural aggregates have relative densities between 2.4 and 2.9 (2400 and 2900 kg/m3).
- The density of aggregate used in mixture proportioning computations (not including the voids between particles) is determined by multiplying the relative density of the aggregate times the density of water (1000 kg/m³).

Absorption and Surface Moisture

The absorption and surface moisture of aggregates should be determined using ASTM C 70, C127, C128, and C 566 so that the total water content of the concrete can be controlled and the batch weights determined. The moisture conditions of aggregates are:

- 1. Oven dry
- 2. Air dry
- 3. Saturated surface dry (SSD)
- 4. Damp or wet

Absorption levels

Aggregate	Moisture content at SSD (%)	Free-water content (%)
Coarse	0.2-4	0.5-2
Fine	0.2-2	2-6

Wetting and Drying

Alternate wetting and drying can develop sever strain in some aggregates, and with certain types of aggregate this can cause a permanent increase in volume of concrete and eventual breakdown. Clay lumps and other friable particles can degrade when subjected to wetting and drying cycles. Also, moisture swelling of clay and shales can cause popouts in concrete.

Abrasion and Skid Resistance (ASTM C 131)

- Abrasion resistance of an aggregate is used as a general index of its quality. This characteristic is important when concrete is going to be subjected to abrasion, as in heavy duty floors or pavements.
- Low abrasion resistance may increase the quantity of fines in the concrete during mixing; and hence increases the water requirement and require an adjustment in w/c ratio.
- Los Angeles abrasion test as per ASTM C 131 is the most common test for abrasion test.

Resistance to Acid and other Corrosive Substances

- Acid solutions (pH less than 6.0) attack the calcium compounds of the cement paste, the rate of attack depends on the acidity of the solution. Siliceous aggregates may not be attacked by acidic solutions, however, calcareous aggregates often reacts with acids resulting in reduction of the solution acidity.
- Other gases and salts may attack and disintegrate concrete. Therefore, concrete structures subjected to harsh conditions should be protected and aggressive agents should be prevented from coming into contact with the concrete by using protective coatings.

•

Fire Resistance and Thermal Properties

- The fire resistance and thermal properties of concrete depend on the mineral constituents of the aggregates. Lightweight aggregates are more fire resistance than normal weight aggregates due to their insulation properties.
- Concrete containing calcareous coarse aggregates performs better under fire exposure than siliceous aggregate (granite or quartz).

Potentially Harmful Materials

- Aggregates are potentially harmful if they contain compounds known to react chemically with Portland cement and produce:
 - Volume change of the paste, aggregates, or both.
 - Affect the normal hydration of cement.
 - Harmful byproducts.
- Harmful materials present in aggregates are listed in the below Table.

Table 5-6. Harmful Materials in Aggregates

Substances Organic impurities	Effect on concrete Affects setting and hardening, may cause deterioration	Test designation	
		ASTM C 40 ASTM C 87	(AASHTO T 21) (AASHTO T 71)
Materials finer than the 75 μm (No. 200) sieve	Affects bond, increases water requirement	ASTM C 117	(AASHTO T 11)
Coal, lignite, or other lightweight materials	Affects durability, may cause stains and popouts	ASTM C 123	(AASHTO T 113)
Soft particles	Affects durability		
Clay lumps and friable particles	Affects work- ability and durability, may cause popouts	ASTM C 142	(AASHTO T 112)
Chert of less than 2.40 relative density	Affects durability, may cause popouts	ASTM C 123 ASTM C 295	(AASHTO T 113)
Alkali-reactive aggregates	Causes abnormal expansion, map cracking, and popouts	ASTM C 227 ASTM C 289 ASTM C 295 ASTM C 342 ASTM C 586 ASTM C 1260 ASTM C 1293	(AASHTO T 303)

Chapter 6: Admixtures for Concrete

Definition

A material other than water, aggregates and hydraulic cement that is used as an ingredient in concrete or mortar and is added to the batch immediately before or during its mixing (ASTM C125).

Reasons for using Admixtures

- reduce cost of concrete construction.
- Achieve certain properties more effectively than by other means.
- Ensure quality of concrete during stages of mixing, transporting, placing and curing in adverse conditions.
- Overcome certain emergencies during concreting.
- Improve or modify some or several properties of portland cement concrete.
- Compensate for some deficiencies.
- ◆ Increase workability without increasing water content or to decrease water content at the same workability
- Retard or accelerate the time of initial setting
- ◆ Create slight expansion

Modification of Fresh Concrete

- ◆ To modify the rate, or capacity for bleeding or both
- ◆ to improve segregation
- to improve penetration and increase pumpability
- ◆ reduce the rate of slump loss

Modify Hardened Concrete Properties

- ◆ Accelerate the rate of strength gain
- ♦ increase ultimate strength
- ♦ increase durability
- ◆ reduce permeability
- ◆ compensate for shrinkage
- inhibit corrosion

Note: Admixtures are not a solution for poor mix design nor sloppy concrete practice. They are aimed

at providing a more economical solution and enhanced concrete properties.

General Groupings of admixtures

Air-entraining agents:

There are used primarily to improve freeze-thaw durability.

Chemical Admixtures: There are water soluble compounds added primarily to control setting and early hardening of fresh concrete or to reduce the water requirements.

Mineral admixtures:

There are finely divided solids to improve workability, durability, or provide additional cementing properties. (i.e. slags, silica fume, fly ash, and pozzolans).

Miscellaneous admixtures: Those admixtures that don't fall under the above categories.

Precautions in use of admixtures:

- 1. Require admixtures to conform to relevant ASTM specifications, where applicable. Tech. data should include:
 - a. main effect of admixture.
 - b. any additional influences admixture may have.
 - c. physical properties of the material.

- d. concentration of active ingredient.
- e. presence of any potentially detrimental substances such as chlorides, sulphates etc.
- f. pH
- g. potential occupational hazards for users.
- h. conditions for storage and shelf life.
- i. instructions for preparation of admixture and procedures for introducing it into the concrete mix.
- j. recommended dosage under identified conditions, max permissible dosage, and effects of over-dosage.
- 2. Follow recommended dosage, but run relevant tests to confirm effects with the same materials as will be used in the field.
- 3. Ensure reliable procedures are established for accurate batching of the admixture, especially with chemical admixtures which may have dosages below 0.1% by weight of cement. (Overdoses can easily occur with disastrous results)
- 4. Be aware of the effects the admixture can have on other concrete properties as most affect several concrete properties.

CONCRETE ADMIXTURES CLASSIFICATION

- 1. Air-entraining admixtures
- 2. Water-reducing admixtures
- 3. Retarding admixtures
- 4. Accelerating admixtures
- 5. Superplasticizers
- 6. Finely divided mineral admixtures
- Miscellaneous admixtures such as workability, bonding, dampproofing, permeability-reducing, grouting, gas-forming, coloring, corrosion inhibiting, and pumping admixtures

Chemical Admixtures

- Type A: Water-reducing (WR)
- Type B: Set retarding (SR)
- Type C: Set accelerating (SA)
- Type D: WR + SR
- Type E: WR + SA
- Type F: High-range water-reducing (HRWR)
- Type G: HRWR + SR

Mineral Admixtures

- Raw or calcined pozzolans
- Fly ash produced from burning bituminous coal
- Fly ash normally produced from burning lignite (subbituminous) coal. (both pozzolanic and cementatious).

Air Entraining Admixtures

Air entrainment refers to the introduction of large quantities of tiny air bubbles in the concrete matrix. The main reason for air entrainment is to improve the durability of the concrete to freezethaw degradation.

The Air-Void System

As un-reacted water freezes it expands 9 % by volume on phase change. This internal volume expansion causes internal stresses in the matrix. It can generate cracks in the concrete, which may allow water to infiltrate and the process can get progressively worse. It can lead to significant degradation of the concrete.

The formation of ice in the pore spaces generates pressure on any remaining unfrozen water. Introducing a large quantity of air bubbles provides a place for this water to move in to relieving the internal pressure. What is desired is to generate very many small air bubbles well distributed throughout the matrix rather than a smaller number of larger bubbles.

It's been determined that the optimum air content for frost protection is about 9% by volume of the mortar fraction. With respect to the concrete volume, the air content should

be in the range of 4-8% by volume. The concrete normally has entrained air, the admixture increases the total volume of the air voids by 3-4% of the concrete volume.

Total air content is only a part of the formula for frost resistance. The nature of the entrained air is equally important. The critical parameter of the air-entrained paste is the spacing factor (max distance from any point in the paste to the edge of a void). It should not exceed 0.2 mm; the smaller the spacing factor the more durable the concrete.

The air bubbles themselves should be in the range of 0.05 - 1.25 mm in diameter.

Air Entraining Materials

What is needed is an agent that causes the water to foam into a very small matrix of very small bubbles. The admixtures are of the same family as household detergents, but these do not generate small enough bubbles and are not stable enough.

Air entraining agents contain surface-active agents or surfactants. These lower the water surface tension so bubbles can form, and stabilize the bubbles once they are formed.

Increasing the admixture dosage will increase air content, decrease bubble size, and decrease spacing factor. Thus decreasing the total strength of the concrete.

Effect of Air on Other Concrete Properties

- Increase workability and cohesiveness of fresh concrete.
- Considerable reduction in bleeding and segregation.
- Decreased strength (10-20% for most air entrained concrete)
- Increased durability (up to ~7% air; SEE FIG 7.6 Mindess)

- If a lower *w/c* ratio is used to account for the increased slump, some of the strength reduction will be offset.
- In addition, the lower w/c ratio that can be used and the better compaction
- characteristics results in more impermeable concrete and a better overall resistance to
- aggressive agents (i.e. sulfates).

Chemical Admixtures

Water-Reducing Admixtures

These admixtures **lower the water required to attain a given slump**, thus lowering the w/c ratio. This will:

- Improve the strength
- Improve the water tightness
- Improve durability.

Alternately it may be used to maintain the same w/c ratio but increase workability for difficult placement.

Typical reductions in water requirements are 5-10%

There are admixtures called "superplasticizers" or "high-range water reducers" which can reduce water contents by 15-30%.

The water reducers reduce the electronegative charges on the fine cement particles allowing them to disperse more readily in the water. (Similar to the use of Calgon in hydrometer tests). This reduces the tendency for flocculation of the cement particles in the paste.

Composition

Three General Categories

1. salts and derivatives of lignosulfonates.

- 2. salts and derivatives of hydroxycarboxylic acids.
- 3. polymeric materials.

Superplasticizers

These are linear polymers containing sulfonic acid groups.

Two major commercial formulations

- 1. sulfonated melamine-formaldehyde condensate; and
- 2. naphthalene sulfonate-formaldehyde condensate

Effect on Other Concrete Properties

Fresh Concrete

- Improved workability of fresh concrete (flowing concrete with use of superplasticizers, **SP**)
- Some types may increase bleeding (hydroxycarboxylic acids).
- They tend to increase air entrainment (so less air entraining admixture can be used)
- Tend to retard set times.
- Rate of slump loss increases with normal-range water reducers about same for superplasticizers.

Hardened Concrete

- Increased compressive strength due to ability to reduce w/c ratio and better dispersion of cement in paste
- Increased durability due to lower w/c ratio.
- SP Rapid strength gain without increased heat generation.
- SP used for high strength concrete.

Chapter 6: Admixtures for Concrete

Retarding Admixtures

Generaly used for:

- 1. offset effects of high temperature which can decrease setting time.
- 2. avoid complications when unavoidable delays may occur between mixing and placing.
- 3. Resist cracking of recently poured concrete due to form deflection during successive pours.

The retarders slow the rate of early hydration of C3S by extending the length of the dormant period. They also tend to retard the hydration of C3A phases.

Delaying the introduction of the retarders until the concrete has been mixed (up to about 10 min) can enhance its performance. This is because some of the hydration reactions have already occurred and this allows the more of the retarder to react with the C3S.

Subsequent hydration may be more rapid, however, so strength development may not be slower than the unretarded mix. However overdosing may stop C3S hydration completely and the paste will never set.

The degree of effect of retarders can depend on the composition of the particular cement being used. It depends on the aluminate/sulfate ratio in the cement, and possibly the alkali oxides content.

Composition

- 1. salts and derivatives of lignosulfonates.
- 2. salts and derivatives of hydroxycarboxylic acids.
- 3. sugars and their derivatives (a bag of sugar mixed in a truck of concrete can stop the set in case of emergency!).
- 4. inorganic salts.

Note 1&2 are also water reducers.

Effects on Concrete Properties

- 1. Delay the set of the concrete.
- 2. Because some are water reducers, they may increase the amount of entrained air.
- 3. Increase slump.
- 4. They may increase the rate of slump loss though the set has been retarded thus decreasing the time available for placing.

Accelerating Admixtures

General

These are used to increase the rate of strength gain of the concrete.

They are used to speed construction permitting earlier removal of formwork, earlier finishing of surfaces, or earlier load carrying capacity.

These also include admixtures for quick-setting applications, in a few minutes (like shotcreting, plugging leaks and emergency repairs).

They can also be beneficial for cold-weather concreting.

Composition

There are 2 general Groups:

- 1. soluble inorganic salts (CaCl, carbonates, aluminates, fluorides, and ferric salts)
- 2. soluble organic compounds (triethanolamine, calcium formate, calcium acetate)

Calcium chloride is the most popular choice due to low cost and high rate of acceleration for a given dosage.

Sodium carbonate and sodium aluminates are the most common for shotcreting.

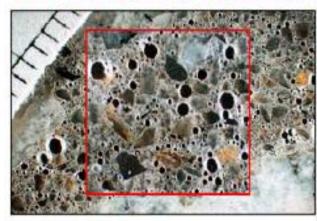
The organic accelerators are most commonly used with water-reducers to offset the retarding affects.

Effect on Concrete Properties:

- They have the exact opposite effect of retarders; they increase the rate of hydration of C3S by shortening the dormant period and also may increase the rate of hydration later on.
- Organic accelerators are believed to increase the rate of hydration of the C3A.
- Quick-setting admixtures are believed to cause flash setting of C3A.
- Expect little effect on air entrainment (though trial batches should be done)
- Less time for placing and handling will result.
- Higher 1- and possibly 7-say strengths will be realized

- There may be a reduction in 28-day strength
- Use of CaCl reduces concrete resistance to sulfate attack and aggravates alkali aggregate reaction
- Quick-setting admixtures will reduce durability
- CaCl may increase the rate of corrosion of reinforcing steel, though the levels of allowable CaCl has not been agreed upon.
- Typically up to 2% CaCl by wt of dry cement have been used in reinforced concrete if adequate cover of dense concrete in provided.
- General agreement that CaCl should not be used in prestressed applications.

Air-Entrained Concrete

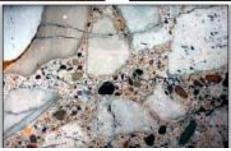




Freeze-Thaw Deterioration







Products by Category: High Range Water Reducers

High Range Water Reducers	▼
High Range Water Reducers	
Sikament 686 Sikament 686 is a high range water reducer utilizing Sika's ViscoCrete Technology. It's unique formulation is based on polycarboxylate technology. Sikament 686 meets the requirements for ASTM C-494 Types A and F.	Technical Data MSDS
Sikament 711	
Sikament 711 is a high range water reducing and superplasticizing admixturefor use in concretes and mortars formulated to provide superior finishability. It is based on Sika's patented 'ViscoCrete' polycarboxylate polymer technology. Sikament 711 meets the requirements for ASTM C-494 Types A and F.	Technical Data
Sika ViscoCrete 2100	
Sika ViscoCrete 2100 is a high range water reducing and superplasticizing admixture utilizing Sika's 'ViscoCrete' polycarboxylate polymer technology. Sika ViscoCrete 2100 meets the requirements for ASTM C-494 Types A and F.	Technical Data MSDS
Sika ViscoCrete 2110	
Sika ViscoCrete 2110 is a high range water reducer and superplasticizer utilizing Sika's ViscoCrete' polycarboxylate polymer technology. Sika ViscoCrete 2110 meets the requirements for ASTMC-494 Types A and F and AASHTO M-194 Types A and F.	Technical Data MSDS
Sika ViscoCrete 4100	
Sika ViscoCrete 4100 is a high range water reducing and superplasticizing admixture utilizing Sika's 'ViscoCrete' polycarboxylate polymer technology. Sika ViscoCrete 4100 meets the requirements for ASTMC-494 Types A and F.	Technical Data MSDS
Sika ViscoCrete 6100	
Sika ViscoCrete 6100 is a high range water reducing and superplasticizing admixture utilizing Sika's 'ViscoCrete' polycarboxylate polymer technology. Sika ViscoCrete 6100 meets the requirements for ASTMC-494 Types A and F.	Technical Data MSDS

Chapter 6

Mixing, Handling, Placing, and compacting concrete

1.Batching:

Batching of aggregates and cements is best done by weight since dispensing of solids on a volume basis can lead to gross errors.



2. Mixing:

The objective of mixing which is done either by rotation or stirring, is to coat the surface of all the aggregate particles with cement paste, and to blend all the ingredients of concrete to a uniform mass.

Mixing time:

The optimum mixing time depends on the type and size of mixer, on the speed of rotation, and on the quality of blending of ingredients during charging the mixer. Concretes made with rounded gravels need less mixing time than those made with angular aggregates.

A good rule of thumb is 1min of mixing time for 1m³ of concrete plus 1/4 min for each additional 1m³.

charging the Mixer:

- 10% of the mixing water is added before the aggregates are added.
- The water is added uniformly during the whole time the solid ingredients are added, leaving about 10% to be added at the end.
- The cement should enter the mixer after about 10% of the aggregates have been charged.
- Mineral admixtures are generally added to the cement.
- Water-soluble admixtures should be dissolved in the mixing water.





Prolonged Mixing:-

- ♣ If mixing is done over a long period of time.
- **Lesson** Evaporation of water form the mix can occur.
- Decreasing the workability while at the same time increasing the strength of the mix.
- ♣ Prolonged mixing reduces the air content of the mix, which is a disadvantage in case of airentrained concrete (freeze and thaw resistant).

Mixers:-

The usual type of mixer is a batch mixer, which means that one batch of concrete is mixed and discharged before any more materials are put into the mixer.

There are four types of batch mixers:

a. Tilting drums mixer: are common used for small jobs, are also available in large sizes. and have an arrangement of interior fixed blades to ensure end-to-end exchange of material during mixing.



b. Pan-type mixers: are particularly good for mixing lean and dry mixers. They are commonly used in precast concrete plants, where their greater bulk and less convenient discharge are not necessarily disadvantages.



c. Continuous mixer: the materials are fed into a mixing trough by means of conveyors. The concrete is mixed by a spiral blade as it passes through the trough to the discharge end.

Ready Mixed concrete:

It is delivered for placing form a central plant.

Advantages:-

☑ close quality control.

- **☑** Elimination of materials storage on building site.
- use of truck mixers ensures care in transportation, thus preventing segregation and maintaining workability.
- **⊠** convenient when small quantities of concrete or intermittent placing is required.

The cost of ready-mixed concrete, since it is a bought commodity, is some what higher than that mixed at the site, but this is often offset by savings in site organization, in supervising staff, and in cement content.

Mixing methods:-

There are several ways in which concrete from central batching plants can be handled.

Central-mixed concrete, is completely mixed at the plant, and the truck mixer is only used as an agitating conveyance.

Transit-mixed concrete, is partially or completely mixed during the time the concrete is being transported to the job site.

Shrink-mixed concrete, is partially mixed at the plant to shrink or reduce the overall volume, and mixing is completed in the truck mixer.

Truck- mixed concrete, is completely mixed within the mobile mixer after it has been charged at the central plant. The advantages of truck mixing is that the water can been kept separate from the solid materials and mixed just prior to placement at the construction. Problems of delays in transportation or placement are avoided.

3. Transporting:-

- After being mixed, concrete is transported to the site in such away to prevent segregation and to keep the mix uniform.
- On small jobs two wheeled carts are used for transporting concrete.
- On large projects cable cars, covey or belts, towers, and pumps may be used.
- Any method of transportation should protect the concrete from the effect of weather.
- Buckets should be designed so that discharge can be properly regulated so that segregation does not occur during discharge.
- The bucket should slope down to the exit gate and the concrete should be released vertically.

4. Pumping:-

Nowadays, large quantities of concrete can be transported by means of pumping through pipelines over quite large distances which are not accessible by other means. (up to 450m horizontally and 150m vertically).

The pumping system consists of a hopper into which concrete is discharged from the mixer, a concrete pump, and the pipes through which the concrete is pumped.

pump types:-

- A. <u>Piston pumps:</u> concrete is forced using a piston and inlet and outlet valves. (up to 60m³ per hour through a 22m diameter pipe up to 450m horizontally or 40m vertically).
- B. <u>Pneumatic pumps:-</u> concrete is forced through line by means of compressed air.
- C. <u>Squeeze pumps:-</u> concrete is forced through the line by means of rollers. (up to 90m hori3ontally & 30m vertically).

General Notes:-

- The pipe diameter must be at least three times the maximum aggregate size.
- ❖ A slump of between 4cm and 10cm is generally recommended for the mix to be pumped.
- The optimum situation is when there is a minimum frictional resistance against the pipe walls, and a minimum content of voids within the mix (continuous aggregate grading).
- ❖ The requirements of consistency are necessary to avoid excessive frictional resistance in the pipe with too-dry mixes, or segregation with too-wet mixes.
- Concrete pipelines can be made either of rigid pipe or heavy-duty flexible hose-long flexible hoses are difficult to hand compared with the rigid ones.

Couplings between pipe sections should be watertight, strong enough to withstand stresses from misalignment or poor pipes support, present no obstruction to concrete, and can be easily connected or disconnected.

Pumping distances:

- ✓ The distance concrete can be pumped depends on many factors, including the capacity of the pump, the size of the pipelines, the number of obstructions to uniform flow, the velocity of pumping, and the characteristics of the concrete.
- ✓ The pump must supply enough force to overcome frictional losses resulting from: surface friction on the walls of the pipelines, bends in the line, and decreases in diameter.
- ✓ When concrete is pumped vertically, extra force in needed to overcome gravity.

5. Placing:-

As far as placing is concerned, the main objective is to deposit the concrete as close as possible to its final position so that segregation is avoided and the concrete can be fully compacted.

The following principles are to be followed:

- 1. Hand shoveling and moving concrete by pocker vibrators should be avoided.
- 2. Concrete is to be placed in uniform layers, not in large heaps or sloping layers.

- 3. The thickness of a layer should be compatible with the method of vibration so that entrained can be removed from the bottom of each layer.
- 4. The rates of placing and compacting should be equal.
- 5. Each layer should be fully compacted before placing the next one, and each subsequent layer should be placed whilst the underlying layer is still plastic so that the monolithic construction is achieved.
- 6. Collision between concrete and formwork or reinforcement should be avoided.
- 7. Concrete should be placed in a vertical plane.
- 8. When placing in horizontal or sloping forms, the concrete should be placed vertically against, and not away from the previously placed concrete. Thus if any segregation has occurred during transporting the concrete or during placing.
- 9. Concrete should not be allowed free fall for long distances.
- 10. In deep narrow forms, placing concrete by pump and hose is an advantage. Otherwise, concrete can be placed in the lower part of the form through opening specially made for this purpose.

Chapter 6:

Mixing, Handling, Placing, and compacting concrete

Special placement:

In this section, casting in lifts, slip forming, preplaced aggregate, shorcreting, tremie concreting and underwater placement will be covered.

1. Casting in lifts:

- Deep placement should be cast in successive horizontal layers or lifts.
- Adjacent lifts should be knitted together by ensuring that the internal vibrators pass into the lower lifts.
- Successive lifts should not be more than 60cm thick, and should be a lot less than that when external vibrators are used.
- ❖ When the concrete in a lift hardens before the next lift can be placed, a construction joint will result, since the two layers can be no longer consolidated together.

2. Slip forming:

- It is a continuous process of placing and compacting low workability concrete.
- Both horizontal and vertical slip forming is possible, vertical slip forming is lower, requiring formwork until sufficient strength has been

- gained to support the new concrete and the form above.
- It is used in the construction of silos, chimneys, monolithic tunnel linings, and high-rise construction.
- This arrangement will decrease the construction time as there is no need for stripping and resetting.
- Slip forms are in general built up of sections which could be raised or lowered by the help of jacks or screws.
- This is done by means of arranging guiding rails as which steel rods or pipes, well braced together to carry the forms continuously in the required direction.
- Surfaces of forms (internal) are to be oiled before concreting to prevent sticking or dragging of concrete during moving the forms.

3. Preplaced aggregates:

- This type of placing is used in locations not accessible by, or suitable for ordinary concreting techniques.
- Coarse aggregate is placed and compacted in the forms, and then the voids forming about 33% of the overall volume, are injected with mortar)gap graded aggregates).
- The mortar is pumped under pressure slotted pipes, usually about 3.5cm in diameter and placed at 2cm center-to-center.
- The pipes are gradually withdraw as the mortar level rises.
- No internal vibration is needed but external vibration at the level of the top of the mortar may improve the exposed surfaces.

4. Shortcreting:

- Concrete is applied pneumatically at high velocity from a nozzle.
- It is used for thin lightly reinforced sections, such as shells or folded plate roofs.
- It is also used for repairing deteriorated concrete, in stabilizing rock slops, and in encasing steel for fire roofing.
- The force of the jet compacting on the surface compacts the material so that it can support itself without sagging even on a vertical face or overhead.
- Shortcrete is sprayed on backup surface and then gradually built up to thicknesses of up to 10 cm, only one side of formwork is needed.
- On the other hand, the cement content of shortcrete is high and the necessary equipment and mode of placing are more expensive than in the case of conventional concrete.

5. Tremie Placing:

- It is particularly suited for deep forms, where compaction by the usual methods is not possible and for underwater concreting.
- High workability concrete is fed by gravity through a vertical pipe which is gradually raised. The method is advantageous where minimal surfaces disturbance is needed, especially when a concrete water interface exists. (see fig11.11 p267).
- The mix should be cohesive, without segregation or bleeding, and usually has a high cement content, a high proportion of fines (40-50%), and contains a workability aid(admixture).

- The slump of such a mix should range between 15 and 25cm.
- For successful tremie placement, a steady uninterrupted flow of concrete through the tremie pipe should be maintained.

6. <u>Underwater placement:</u>

Special dump buckets have been designed for underwater placement. Such a bucket has skirts which are lowered while the concrete is discharged to protect it from the surrounding water.

6. Compacting:

- Concrete should be worked to eliminate the voids and entrapped air to consolidate the concrete into the corners of the forms and around the reinforcing steel.
- Nowadays, compacting or consolidating concrete is done by vibration proper vibration allows the use of stiffer mixes, leads to better consolidation, and gives a better finish.
- With the use of vibration as a compaction method, slump as little as one-third of those consolidated by hand can be used.
- Vibration is needed for proper compaction of concrete with less than 5cm slump.
- Over consolidation brings excess paste to the surface, leading to extra bleeding, and causes loss of entrained air.
- The time of vibration for proper consolidation is about

Chapter 6: Concrete Construction Practices

The production of high-quality concrete does not rest solely on proper proportioning. The concrete placed in a structure must be of uniform quality, free of voids and discontinuities and adequately cured.

Lack of sufficient attention to mixing, handling, and placing can result in poor concrete from a well-designed mix.

Batching and mixing

Batching

Batching of aggregates and cements is best done by weight, since dispensing of solids on a volume basis can lead to gross errors. Only water and liquid admixtures can be measured accurately by volume.

Look at Figure 11.1 of your text book for handling and string aggregates, figure 11.2 for methods of batching.

Mixing

Thorough mixing is essential for the complete blending of the materials that are required for the production of homogeneous, uniform concrete. Not only does inadequate mixing result in lower strengths, but also in greater batch-to-batch and within-batch variations. However, overly long mixing times do not

improve the quality of concrete and may severely limit the output of the batching plant.

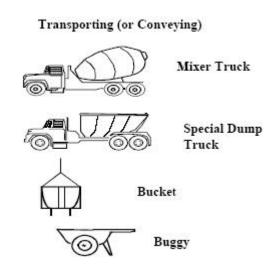
The optimum mixing time depends on:

- 1. The type of mixer.
- 2. The condition of the mixer.
- 3. The speed of rotation.
- 4. The size of the charge.
- 5. The nature of the constituents.

Lean, dry or harsh mixes require more mixing than those made with rounded gravels.

Transportation

Placement of Concrete





Concrete hopper truck at a concrete mixing plant



Side-dumping trucks for highway construction



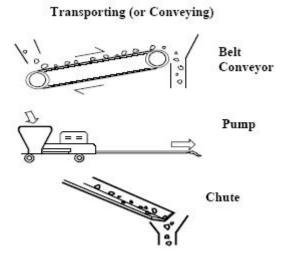
Flat-bed dump truck for highway construction



Ready-mix truck at a concrete batch plant



Use of a mobile concrete batching and mixing truck to produce concrete at the job site





Use of boom and pump to place concrete to a wall



Conveying concrete by pumping



Using a tower crane and a bucket for conveying concrete



Concrete bucket suspended from a crane





Using a chute to deliver concrete

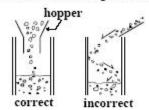


A flat-bed dump truck delivers concrete directly to the pavement bed

PLACEMENT OF CONCRETE

Practices that reduce segregation

(1) Avoid concrete hitting the form by using a hopper.



- (2) Avoid concrete running down a slope
- (3) Use a baffle and drop at the end of a chute



Placing pumped concrete

Chapter 7: Properties of Fresh Concrete

Fresh concrete: from time of mixing to end of time concrete surface finished in its final location in the structure

Operations: batching, mixing, transporting, placing, compacting, surface finishing

Treatment (curing) of in-placed concrete 6-10 hours after casting (placing) and during first few days of hardening is important.

Fresh state properties enormously affect hardened state properties.

- The potential strength and durability of concrete of a given mix proportion is very dependent on the degree of its compaction.
- The first 48 hours are very important for the performance of the concrete structure.
- It controls the long-term behavior, influence f'c (ultimate strength), Fc' (elastic modulus), creep, and durability.

Main properties of fresh concrete during mixing, transporting, placing and compacting.

- Fluidity or consistency: capability of being handled and of flowing into formwork and around any reinforcement, with assistance of compacting equipment.
- Compactability: air entrapped during mixing and handling should be easily removed by compaction equipment, such as vibrators.
- Stability or cohesiveness: fresh concrete should remain homogenous and uniform. No segregation of cement paste from aggregates (especially coarse ones)

Fluidity & compactability known as workability

Higher workability concretes are easier to place and handle but obtaining higher workability by increasing water content decreases strength and durability

Compaction of Concrete

Finishing of Concrete





Workability

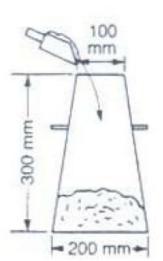
Definition:

- Effort required to manipulate a concrete mixture with a minimum of segregation.
- The amount of mechanical work or energy required to produce full compaction of the concrete without segregation or bleeding.

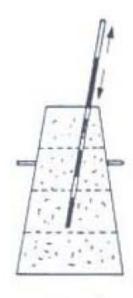
Workability measurement methods

- 1. Slump test
- 2. Compacting factor test
- 3. Vebe test
- 4. Flow table test

1. Slump test - simplest and crudest test



Fill concrete into frustum of a steel cone in three layers



Hand tap concrete In each layer



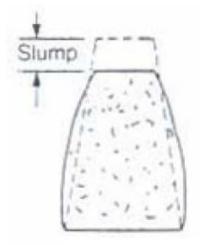
Lift cone up.
Define slump as
downward
Movement of the
concrete



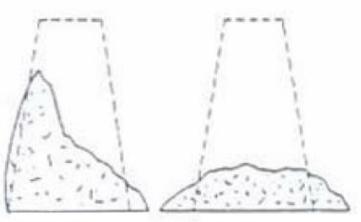
Lift cone up



Define slump as downward movement of the concrete



TrueValid slump
measurement
0-175 mm



Shear Mixes having tendency to segregate – repeat test

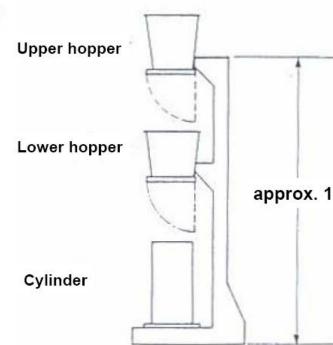
Collapse
Slumps greater than
175 mm - self-leveling
concrete

Consistency grade	Slump (mm)	Recommended method of compaction			
Stiff, K1	0 - 60	Mechanical compaction like vibration			
Plastic, K2	60 – 130	Mechanical or hand compaction (rodding, tampering			
Flowing, K3	130 – 200	Hand compaction or no compaction			
Self compacting, K4	≥ 200	No compaction			

2. Compacting factor test

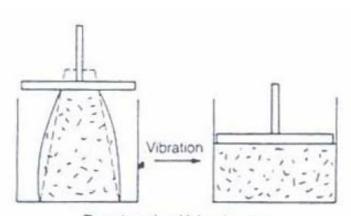
(to distinguish between low slump mixes)

- Concrete is placed in an upper
- Dropped into a lower hopper to bring it to a standard state and then allowed to fall into a standard cylinder.
- The cylinder and concrete weighed (partially compacted weight)
- The concrete is fully compacted, extra concrete added and then conrete and cylinder weighed again (fully compacted weight)



 $Compacting factor = \frac{\text{weight of partially compact concrete}}{\text{weight of fully compact concrete}}$

3. Vebe test



Time (secs) = Vebe degrees

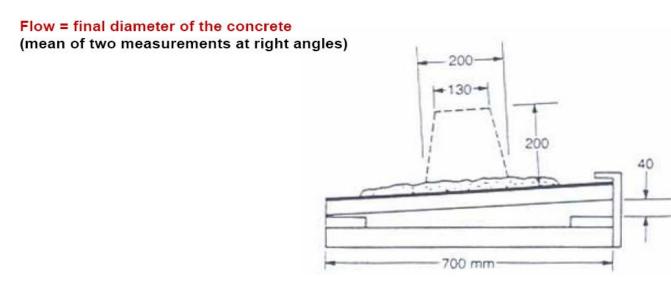
- 1. A slump test is performed in a container
- A clear perspex disc, free to move vertically, is lowered onto the concrete surface
- 3. Vibration at a standard rate is applied

Vebe time is defined as the time take to complete covering of the undersiof the disc with concretecontainer

4. Flow table test

(to differentiate between high workability mixes)

- A conical mould is used to produce a sample of concrete in the centre of a 700 mm square board, hinged along one edge
- 2. The free edge of the board is lifted against the stop and dropped 15 times

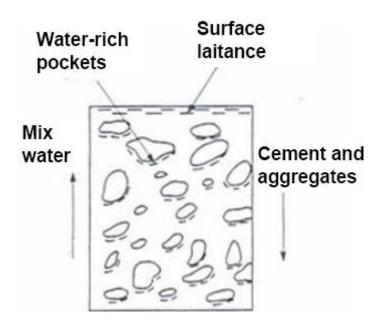


Segregation and Bleeding

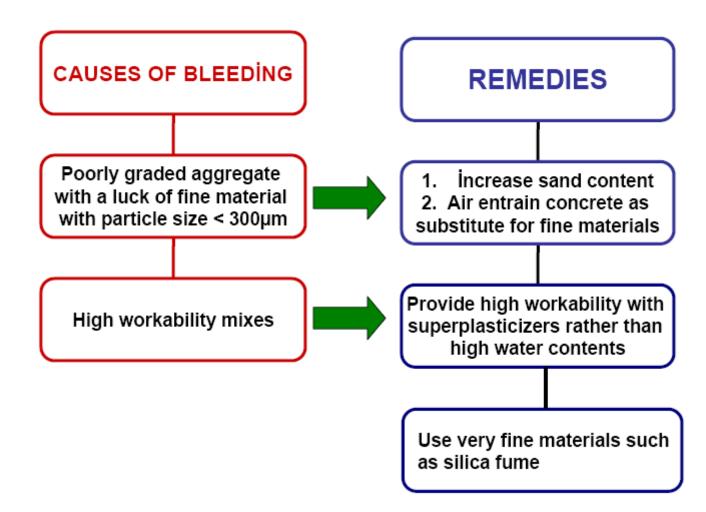
From placing to final set, concrete is in a plastic, semi-fluid state. Heavier particles (aggregates) have tendency to move down (SEGREGATION). Mix water has a tendency to move up (BLEEDING)

BLEEDING

A layer of water (~ 2 % or more of total depth of concrete) accumulates on surface, later this water evaporates or re-absorbed into concrete.



Methods of reducing segregation and bleed and their effects



Chapter 7: Properties of Fresh Concrete (cont.)

Workability: The amount of mechanical work or energy required to produce full compaction of the concrete without segregation or bleeding.

Factors affecting workability

- Water content of the mix.
- Mix proportions.
- Aggregate properties (Max. aggregate size)
- Time and temperature.
- Cement characteristics.
- Admixtures.

Water content of the mix

- The most important factor
- Increasing water increase the ease of flows and compaction.

Reduce strength and

durability.

→ May lead to segregation and bleeding.

- mixing water is divided into three parts
 - 1- adsorbed on the particle surfaces
 - 2- filled the spaces between the particles.
- 3- lubricates the particles by separating them with a film of

water _____ finer particles require more water.

Aggregate properties

There are two important factors here

- 1- amount of aggregates.
- 2- the relative proportions of fine to coarse aggregates.
 - increase of aggregate/cement ratio decreases workability
 - more cement is needed when finer aggregate grading are used.
 - Harsh concrete: deficiency in fine aggregate resulting in lack of the desired consistency resulting in segregation.
 - Shape and texture of aggregate particles.
 - Nearly spherical particles give more workable concrete. Spherical particles give lower surface – to –volume ratio, less mortar to coat the particles, leaving more water to enhance workability.
 - The porosity of the aggregates can absorb a great deal of water and less will be available to provide workability.

Time and temperature.

Considerable evidence that temperature increase will decrease workability as higher temperatures will increase both the evaporation rate and hydration rate. Very warm weather will require more water to maintain the same workability.

Cement characteristics.

Less important factor in determining workability than the aggregate properties.

However, increased fineness of type III (rapid – hardening 0 cements will reduce workability at a given w/c ratio.

Admixtures.

This factor will be explained later

B) Curing

Curing; protection of concrete from moisture loss from as soon after placing as possible, and for the first few days of hardening

Curing methods

- Spraying or ponding surface of concrete with water
- Protecting exposed surfaces from wind and sun by windbreaks and sunshades
- Covering surfaces with wet hessian and/or polythene sheets
- Applying a curing membrane, a spray-applied resin seal, to the exposed surface to prevent moisture loss

Effect of curing temperature

Hydration reactions between cement and water are temperature dependent and rate of reaction increases with curing temperature

At early ages, rate of strength gain increases with curing temperature (higher temperatures increases rate of reaction, thus more C-S-H and gel is produced at earlier times, achieving a higher gel/space ratio and thus higher strength)

At later ages, higher strength are obtained from concrete cured at lower temperatures.

(C-S- H gel is more rapidly produced at higher temperature and is less uniform and hence weaker than produced at lower temperatures)

Standard curing temperature is 22 \pm 1 $^{\rm o}$ C

Hydration proceeds below 0 ° C, stop completely at -10 ° C













Chapter 7: Properties of Fresh Concrete (cont.)

Workability: The amount of mechanical work or energy required to produce full compaction of the concrete without segregation or bleeding.

Factors affecting workability

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- Mix proportions.
- Aggregate properties (Max. aggregate size)
- Time and temperature.
- Cement characteristics.
- Admixtures.

Water content of the mix

- The most important factor
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 Reduce strength and durability.
- → May lead to segregation and bleeding.
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Chapter 8: Proportioning Concrete Mixes

Objective

To determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.

Also, to determine the proportion of ingredients that would produce a workable concrete mix that is durable, and of required strength, and at a minimum cost

Factors to be considered include:

□ Workability.
☐ Cohesiveness, slump.
☐ Placement conditions.
□ Strength.
□ Durability.
☐ Appearance.
□ Economy.
$\hfill \square$ Minimize the amount of cement, Minimize w/c ratio.
$\hfill \square$ Minimum amount of water, to reduce cement content.
☐ do not sacrifice the quality.

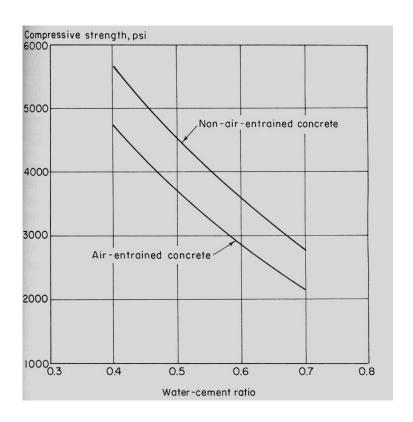
- Economical consideration
 - Minimize water and cement, Stiffest possible mix
 - Largest practical max size of aggregate, Shape, Surface Texture
 - Optimize ratio of fine to coarse
 - Grading (Particle Size distribution, PSD) and its significance, Consistency, Strength, Finishability
- Size and shape of members
 - Max size of aggregate
- Physical properties
 - Strength
- Exposure condition
 - Air entraining or not, sulfate attack
- The most economical mix is the one with the largest possible max size aggregate
- Max size of aggregate
 - < 1/5 of narrowest dimensions of form</p>
 - or ¾ of spacing between rebars
 - or unreinforced slabs < 1/3 thickness

Principles of Mix Design

- Workable mix.
- Use as little cement as possible.
- Use as little water as possible.
- Gravel and sand to be proportioned to achieve a dense mix

- Maximum size of aggregates should be as large as possible, to minimize surface area of aggregates

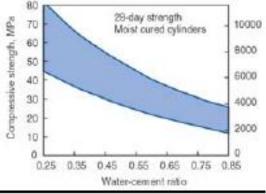
Affect of Water/cement Ratio (w/c ratio)



Water/Cement Ratio

A minimum w/c ratio (water-to-cement ratio) of about 0.3 by weight is necessary to ensure that the water comes into contact with all cement particles (thus assuring complete hydration).

Typical values are in the 0.4 to 0.6



Water/cement ratio (w/c ratio) theory states that for a given combination of materials and as long as workable consistency is obtained, the strength of concrete at a given age depends on the w/c ratio.

In 1918, Duff Abrams established a water/cement ratio law for the strength of concrete:

$$\sigma_c = \frac{A}{B^{1.5(w/c)}}$$

 σ_c = compressive strength at some fixed age, A = empirical constant (96.5 MPa), B= constant that depends mostly on the cement properties (about 4), and w/c (water/cement ratio by weight).

Advant	tages of	low	water	cement	ratio:
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Increased strength.
Lower permeability.
Increased resistance to weathering.
Better bond between concrete and reinforcement.
Reduced drying shrinkage and cracking.
Less volume change from wetting and drying.

Methods of Mix Proportioning

- □ Absolute volume method
 Most commonly used method (ACI mix dsign)
 □ Other methods
- ACI 211.1 Standard practice for selecting Normal, Heavyweight and Mass Concrete.
- ACI 211.2 Standard practice for selecting Structural lightweight concrete.
- ACI 211.3 Standard practice for selecting Proportions for no-slump concrete.
- ACI 211.4R Standard practice for selecting high strength concrete with Portland cement and fly ash.

Designing Concrete Mixtures

Concrete mixture proportions are usually expressed on the basis of the mass of ingredients per unit volume.

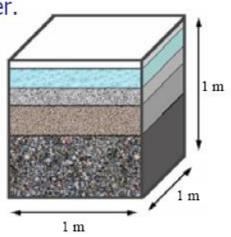
The unit of volume used is either a cubic yard or a cubic meter of concrete.

Material	Volume m ³	Density kg/m ³	Mass kg	Absolute Volume
Air	0.060			
Water	0.150	1000	150	1
Cement	0.111	3150	350	
Sand	0.245	2650	650	
Stone	0.434	2650	1150	1 m
Total	1.000		2300	1 m

 The mixture proportions of concrete are usually written in terms of mass per cubic meter.

Mixture proportions

IIIACAIC	proportions	
Water	150 kg/m ³	
Cement	350 kg/m ³	
Sand	650 kg/m ³	
Stone	1150 kg/m ³	
Air	6%	



Absolute Volume

ACI Mix Design

The most common method used which is established by ACI Recommended Practice 211.1

Any mix design procedure will provide a first approximation of the proportions and must be checked by trial batches.

Local characteristics of materials should be considered.

The following sequence of steps should be followed:

(1) determine the following:

- the job parameters
- aggregate properties
- maximum aggregate size
- slump
- w/c ratio
- admixtures,
- (2) calculation of batch weight, and
- (3) adjustments to batch weights based on trial mix.

The aim of the designer should always be to get concrete mixtures of optimum strength at minimum cement content and acceptable workability.

Once the w/c ratio is established and the workability or consistency needed for the

specific design is chosen, the rest should be simple manipulation with diagrams and tables based on large numbers of trial mixes.

ACI METHOD OF PROPORTIONING CONCRETE MIXES

The ACI Standard 211.1 is a "Recommended Practice for Selecting Proportions for Concrete". The procedure is as follows:

- Step 1. Choice of slump
- Step 2. Choice of maximum size of aggregate
- Step 3. Estimation of mixing water and air content
- Step 4. Selection of water/cement ratio
- Step 5. Calculation of cement content
- Step 6. Estimation of coarse aggregate content
- Step 7. calculation of Fine Aggregate Content
- Step 8. Adjustments for Aggregate Moisture
- Step 9. Trial Batch Adjustments

Step 1. Choice of slump

If slump is not specified, a value appropriate for the work can be selected from the below Table which is reproduced from the text book below*, (note that the table numbers are given from the text book rather than the ACI standard).

Type of Construction	Slump			
Type of Construction	(mm)	(inches)		
Reinforced foundation walls and footings	25 - 75	1 - 3		
Plain footings, caissons and substructure walls	25 - 75	1 - 3		
Beams and reinforced walls	25 - 100	1 - 4		
Building columns	25 - 100	1 - 4		
Pavements and slabs	25 - 75	1 - 3		

Mass concrete	25 - 50	1 - 2	
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Step 2. Choice of maximum size of aggregate.

Large maximum sizes of aggregates produce less voids than smaller sizes. Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete, and of coarse it is the mortar which contains the most expensive ingredient, cement. Thus the ACI method is based on the principle that the MAXIMUM SIZE OF AGGREGATE SHOULD BE THE LARGEST AVAILABLE SO LONG IT IS CONSISTENT WITH THE DIMENSIONS OF THE STRUCTURE.

In practice the dimensions of the forms or the spacing of the rebars controls the maximum CA size.

ACI 211.1 states that the maximum CA size should not exceed:

- one-fifth of the narrowest dimension between sides of forms,
- one-third the depth of slabs,
- 3/4-ths of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pre-tensioning strands.
- **Special Note:** When high strength concrete is desired, best results may be obtained with reduced maximum sizes of aggregate since these produce higher strengths at a given w/c ratio.

Step 3. Estimation of mixing water and air content.

The ACI Method uses past experience to give a first estimate for the quantity of water per unit volume of concrete required to produce a given slump.

In general the quantity of water per unit volume of concrete required to produce a given slump is dependent on the

maximum CA size, the shape and grading of both CA and FA, as well as the amount of entrained air.

The approximate amount of water required for average aggregates is given in Table 10.2.

Table 10.2: Approximate Mixing Water and Air Content Requirements

for Different Slumps and Maximum Aggregate Sizes.

	Mixing \	Mixing Water Quantity in kg/m³ (lb/yd³) for the listed Nominal Maximum Aggregate Size						
Slump	9.5 mm (0.375 in.)	12.5 mm (0.5 in.)	19 mm (0.75 in.)	25 mm (1 in.)	37.5 mm (1.5 in.)	50 mm (2 in.)	75 mm (3 in.)	100 mm (4 in.)
Non-Air-Entrained								
25 - 50 (1 - 2)	207 (350)	199 (335)	190 (315)	179 (300)	166 (275)	154 (260)	130 (220)	113 (190)
75 - 100 (3 - 4)	228 (385)	216 (365)	205 (340)	193 (325)	181 (300)	169 (285)	145 (245)	124 (210)
150 - 175 (6 - 7)	243 (410)	228 (385)	216 (360)	202 (340)	190 (315)	178 (300)	160 (270)	-
Typical entrapped air (percent)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained								
25 - 50 (1 - 2)	181 (305)	175 (295)	168 (280)	160 (270)	148 (250)	142 (240)	122 (205)	107 (180)
75 - 100 (3 - 4)	202 (340)	193 (325)	184 (305)	175 (295)	165 (275)	157 (265)	133 (225)	119 (200)
150 - 175 (6 - 7)	216 (365)	205 (345)	197 (325)	184 (310)	174 (290)	166 (280)	154 (260)	-
	Re	commen	ded Air	Conten	t (percen	nt)		
Mild Exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate Exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe Exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Step 4. Selection of water/cement ratio.

The required water/cement ratio is determined by strength, durability and finishability. The appropriate value is chosen from prior testing of a given system of cement and aggregate or a value is chosen from Table 10.3 and/or Table 10.4.

Table 10.3: Water-Cement Ratio and Compressive Strength Relationship

20 Day Compressive	Water-cement ratio by weight			
28-Day Compressive Strength in MPa (psi)	Non-Air- Entrained	Air-Entrained		
41.4 (6000)	0.41	-		
34.5 (5000)	0.48	0.40		
27.6 (4000)	0.57	0.48		
20.7 (3000)	0.68	0.59		
13.8 (2000)	0.82	0.74		

TABLE 10-4 MAXIMUM PERMISSIBLE
WATER/CEMENT RATIOS FOR CONCRETE IN SEVERE
EXPOSURES

Type of Structure	Structure wet continuously or fequently exposed to freezing & thawing*	Structure exposed to seawater
Thin sections (railings, curbs, sills, ledges, ornamental work) & sections with less than 1-inch cover over steel	0.45	0.40
All other structures	0.50	0.45

^{*} Concrete should also be air-entrained.

Step 5. Calculation of cement content.

The amount of cement is fixed by the determinations made in Steps 3 and 4 above.

weight of cement =
$$\frac{weight \ of \ water}{w \ / c}$$

Step 6. Estimation of coarse aggregate content.

The most economical concrete will have as much as possible space occupied by CA since it will require no cement in the space filled by CA.

Table 10.5: Volume of Coarse Aggregate per Unit Volume for Different Fine aggregate Fineness Moduli

Nominal Maximum	Fine Aggregate Fineness Modulus				
Aggregate Size	2.40	2.60	2.80	3.00	

9.5 mm (0.375 inches)	0.50	0.48	0.46	0.44
12.5 mm (0.5 inches)	0.59	0.57	0.55	0.53
19 mm (0.75 inches)	0.66	0.64	0.62	0.60
25 mm (1 inches)	0.71	0.69	0.67	0.65
37.5 mm (1.5 inches)	0.75	0.73	0.71	0.69
50 mm (2 inches)	0.78	0.76	0.74	0.72

Notes:

- 1. These values can be increased by up to about 10 percent for pavement applications.
- 2. Coarse aggregate volumes are based on oven-dry-rodded weights obtained in accordance with ASTM C 29.

The ACI method is based on large numbers of experiments which have shown that for properly graded materials, the finer the sand and the larger the size of the particles in the CA, the more volume of CA can be used to produce a concrete of satisfactory workability.

Step 7. Estimation of Fine Aggregate Content.

At the completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity can be determined by difference if the "absolute volume" displaced by the known ingredients-, (i.e., water, air, cement, and coarse aggregate), is subtracted from the unit volume of concrete to obtain the required volume of fine aggregate.

Then once the volumes are know the weights of each ingredient can be calculated from the specific gravities.

Step 8. Adjustments for Aggregate Moisture.

Aggregate weights. Aggregate volumes are calculated based on oven dry unit weights, but aggregate is typically batched based

on actual weight. Therefore, any moisture in the aggregate will increase its weight and stockpiled aggregates almost always contain some moisture. Without correcting for this, the batched aggregate volumes will be incorrect.

<u>Amount of mixing water</u>. If the batched aggregate is anything but saturated surface dry it will absorb water (if oven dry or air dry) or give up water (if wet) to the cement paste. This causes a net change in the amount of water available in the mix and must be compensated for by adjusting the amount of mixing water added.

Step 9. Trial Batch Adjustments.

The ACI method is written on the basis that a trial batch of concrete will be prepared in the laboratory, and adjusted to give the desired slump, freedom from segregation, finishability, unit weight, air content and strength.