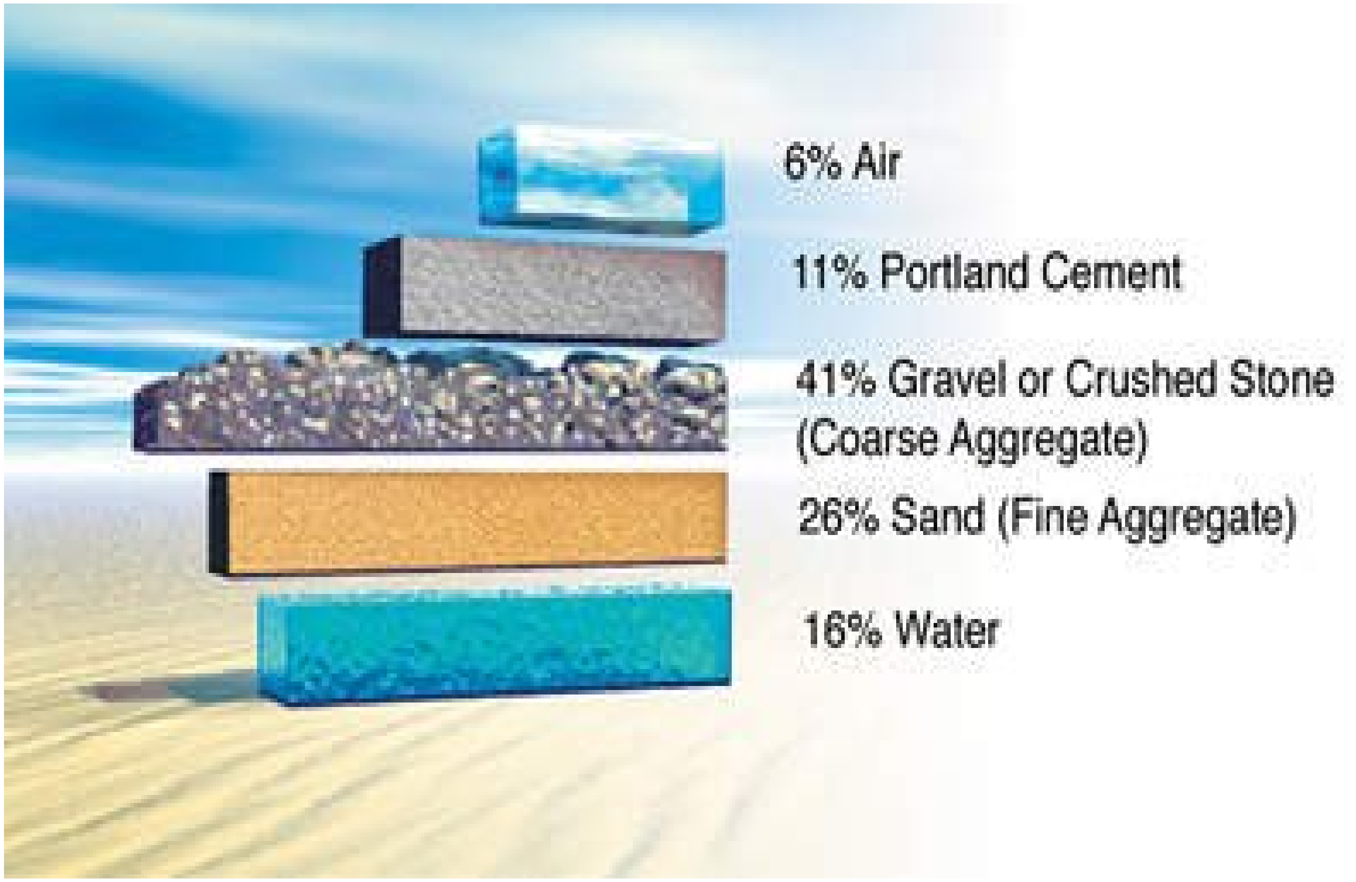
Importance of Portland Pozzolana Cement (PPC) for Durable Construction

Contents

- Introduction
- Durability of Concrete
- Portland Cement
- Blended Cements
- Portland Pozzolana Cement
- Conclusion

Introduction: Concrete

- Is the largest consumed man made material on the earth



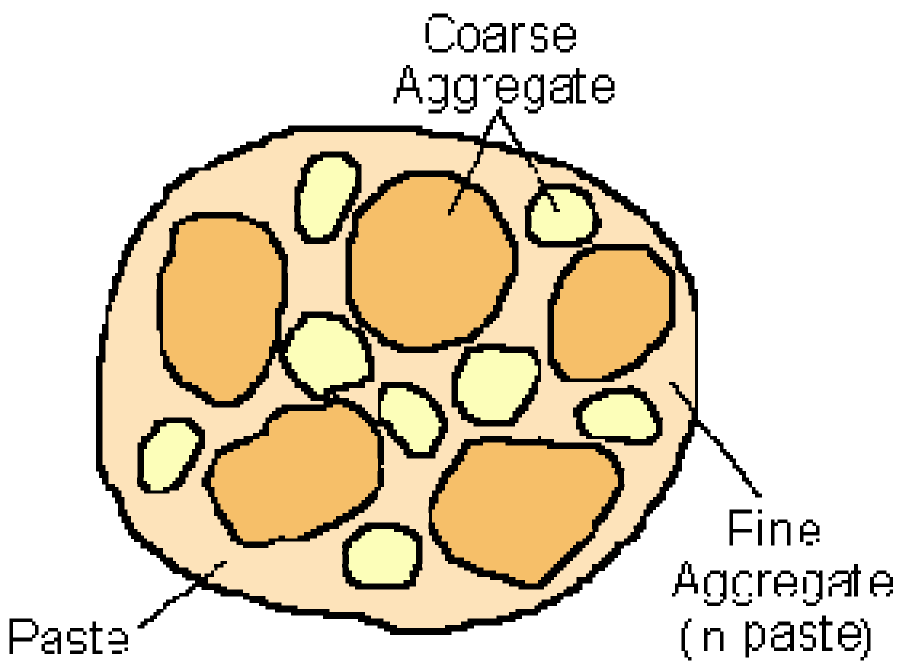
Introduction: Requirements

- Plastic when newly mixed

- Strong and durable,
  when hardened

Introduction: Strong and Durable Concrete

- The key to achieve strong, durable concrete rests on careful proportioning and mixing of the ingredients.



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Introduction: Water

- Why water:

a. Chemical reaction with cement.

b. Workability

- only 1/3 of the water is needed for chemical reaction
- extra water remains in pores and cavities
- results in porosity
- Good for preventing plastic shrinkage cracking and workability
- Bad for permeability, strength, durability

DURABILITY OF CONCRETE

Durability of Concrete 1: Definition

Durability of concrete is the ability of the material and the structure to maintain its level of reliability and serviceability during its lifetime at normal maintenance cost levels.

Durability of Concrete 2

- Durable concrete performs satisfactorily in working environment during its anticipated exposure conditions during service.
- Materials and mix proportions specified /used should be such as to maintain its integrity and, if applicable, to protect embedded metal from corrosion.
- Main characteristics influencing durability is permeability of concrete to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances.

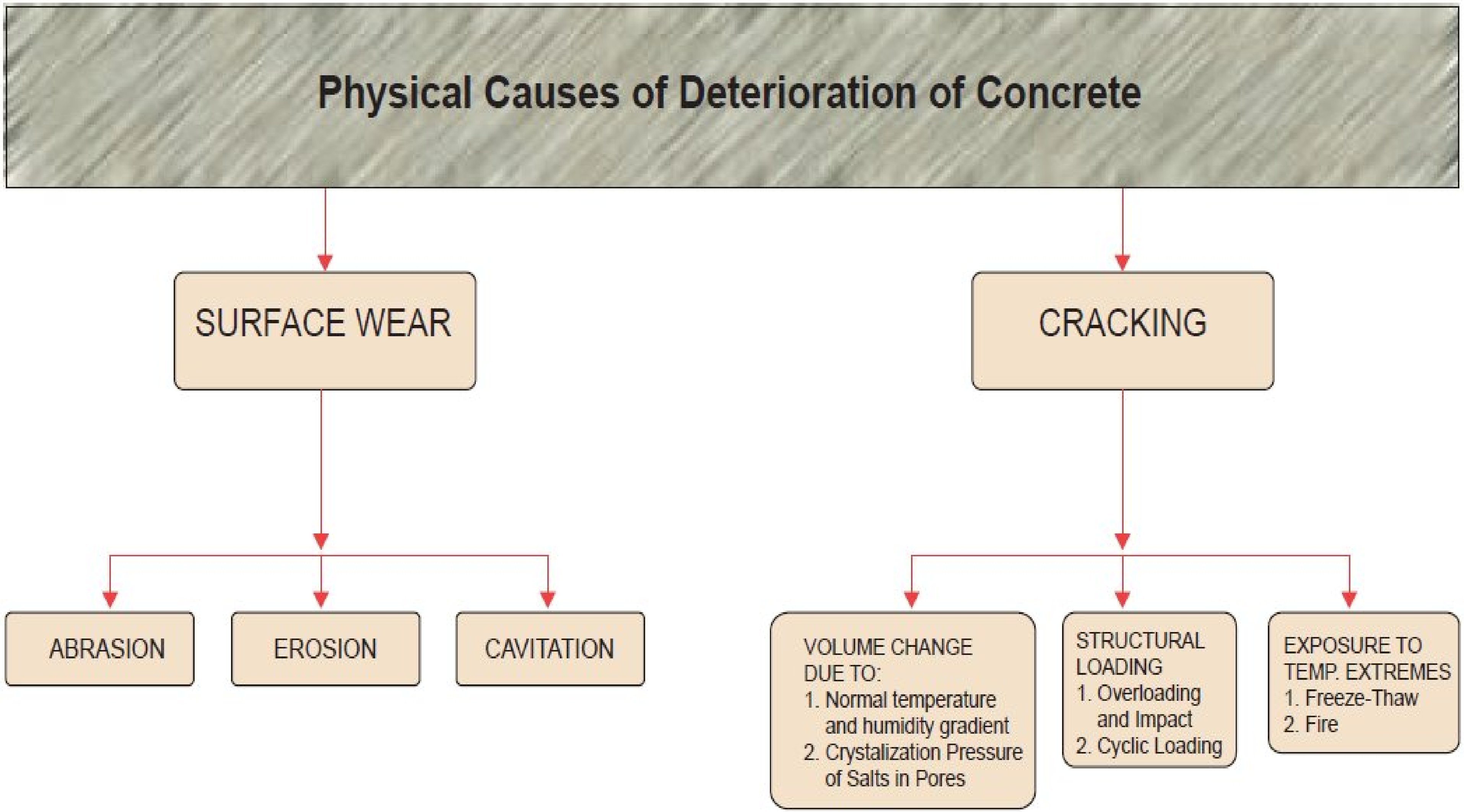
Durability of Concrete 3

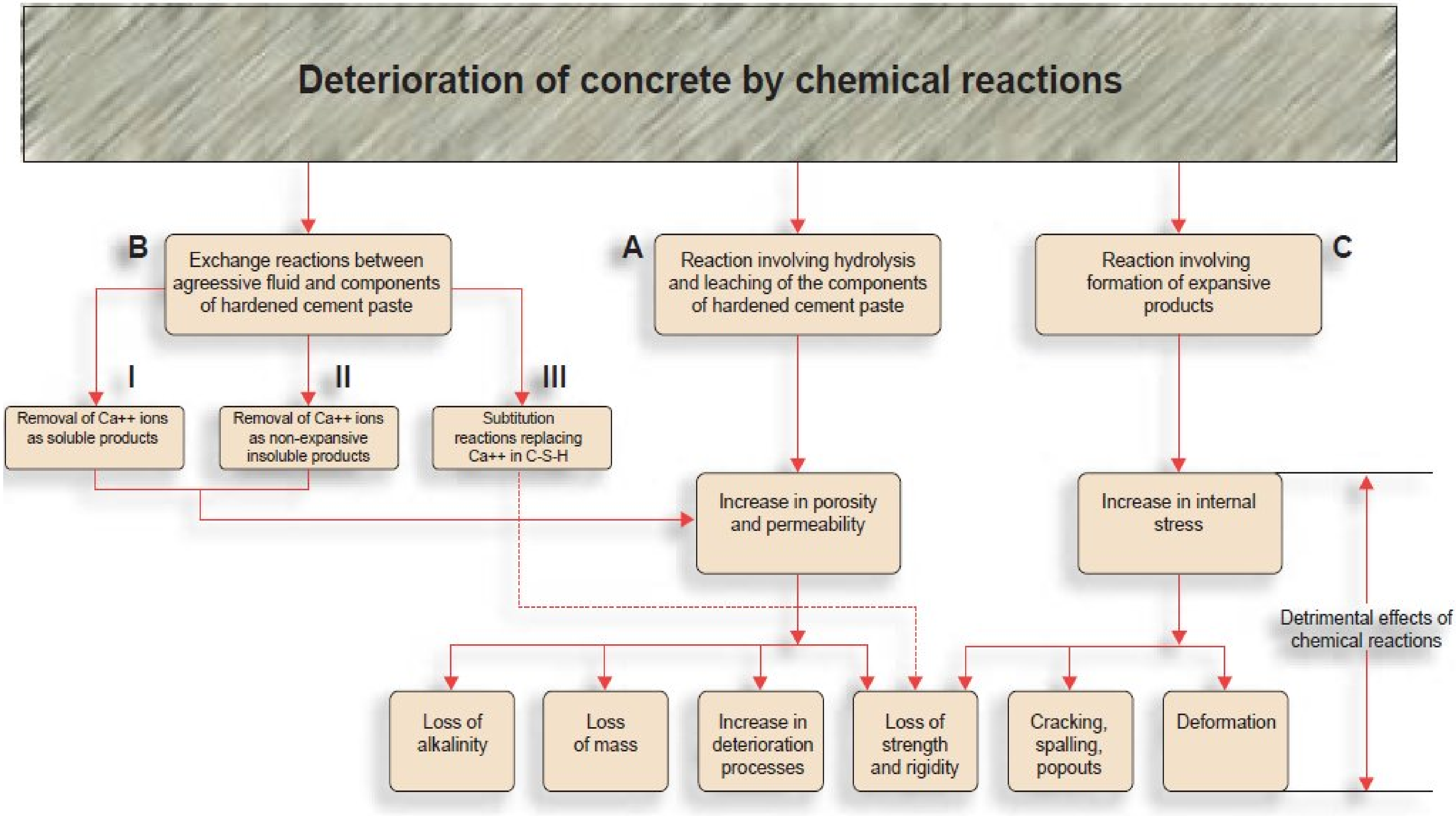
Factors influencing Durability of Concrete

- Environment
- Cover to embedded steel
- Type and quality of constituent materials
- Cement content and water/cement ratio of concrete
- Workmanship: required full compaction and efficient curing
- the shape and size of the member

Environmental Exposure Conditions

Sl No. (1)	Environment (2)	Exposure Conditions (3)
i)	Mild	Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal area.
ii)	Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wet
		Concrete exposed to condensation and rain
		Concrete continuously under water
		Concrete in contact or buried under non-aggressive soil/ground water
		Concrete surfaces sheltered from saturated salt air in coastal area
iii)	Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation.
		Concrete completely immersed in sea water
		Concrete exposed to coastal environment
iv)	Very severe	Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions whilst wet
		Concrete in contact with or buried under aggressive sub-soil/ground water
v)	Extreme	Surface of members in tidal zone
		Members in direct contact with liquid/ solid aggressive chemicals

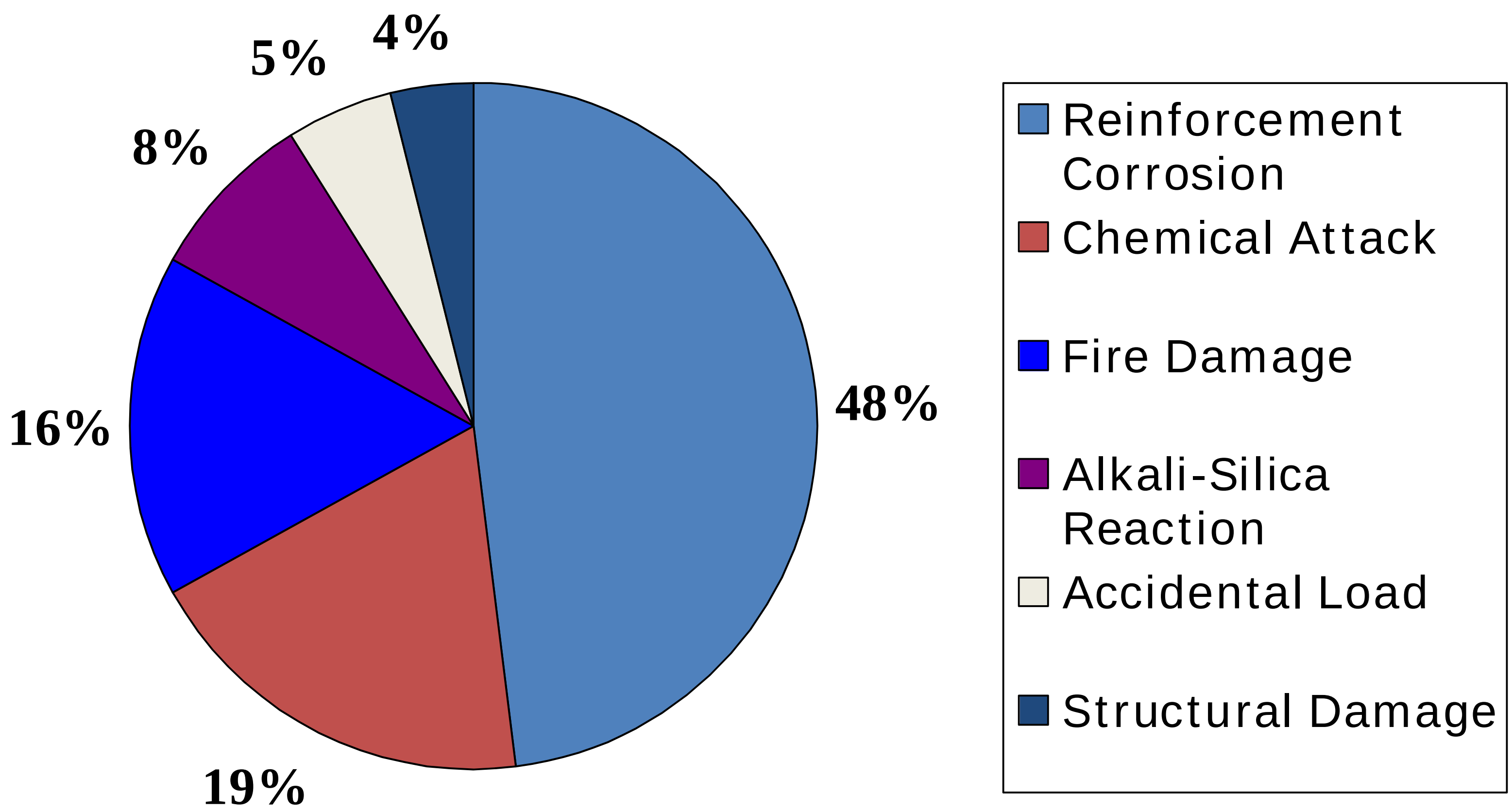

Physical Causes of Deterioration of Concrete
SURFACE WEAR
CRACKING
ABRASION
EROSION
CAVITATION
VOLUME CHANGE DUE TO:
1. Normal temperature and humidity gradient
2. Crystalization Pressure of Salts in Pores
STRUCTURAL LOADING
1. Overloading and Impact
2. Cyclic Loading
EXPOSURE TO TEMP. EXTREMES
1. Freeze-Thaw
2. Fire


Deterioration of concrete by chemical reactions
B
Exchange reactions between agreessive fluid and components of hardened cement paste
A
Reaction involving hydrolysis and leaching of the components of hardened cement paste
Reaction involving formation of expansive products
C
I
II
III
Removal of Ca++ ions as soluble products
Removal of Ca++ ions as non-expansive insoluble products
Subtitution reactions replacing Ca++ in C-S-H
Increase in porosity and permeability
Increase in internal stress
Detrimental effects of chemical reactions
Loss of alkalinity
Loss of mass
Increase in deterioration processes
Loss of strength and rigidity
Cracking, spalling, popouts
Deformation

Durability of concrete 4: Water- the Main Culprit

- Acts as a carrier for deleterious material.
- Leaves vulnerable voids
- Shrinkage problems
- Causes cracks
- Causes segregation, bleeding

Deterioration Mechanism



40 % of Construction Budget for Restoration Life Cycle Cost VS Initial Cost

PORTLAND CEMENT

Portland Cement

It is defined as a hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulphate as an inter-ground addition (ASTM C150).

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Chemical Composition

- Approximate oxide compositions limits of OPC

Oxide	% Content
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-6
MgO	0.1-4
K_2O, Na_2O	0.4-1.3
SO_3	1.3-3.0

Cement Compounds

Process	Tri-calcium Silicate C_3S	Di-calcium Silicate C_2S	Tri-calcium Aluminate C_3A	Tetra-Calcium Alumino-ferrite C_4AF
Sequence of formation of products in kiln	Fourth	Third	Second	First
Rate of reaction of products with water	Moderate	Slow	Fast	Moderate
Strength attained by reaction product formed	High	Initially low, later high	Low	Low
Quantum of heat liberated during hydration process	High	Low	Very High	Moderate

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Calcium Hydrates

$$2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$$

$$2C_2S + 4H \rightarrow C_3S_2H_3 + Ca(OH)_2$$

$$2C_3A + 6H \rightarrow C_3AH_6$$

$$C_4AF_6 \rightarrow CaO\text{-}Al_2O_3\text{-}H_2O$$

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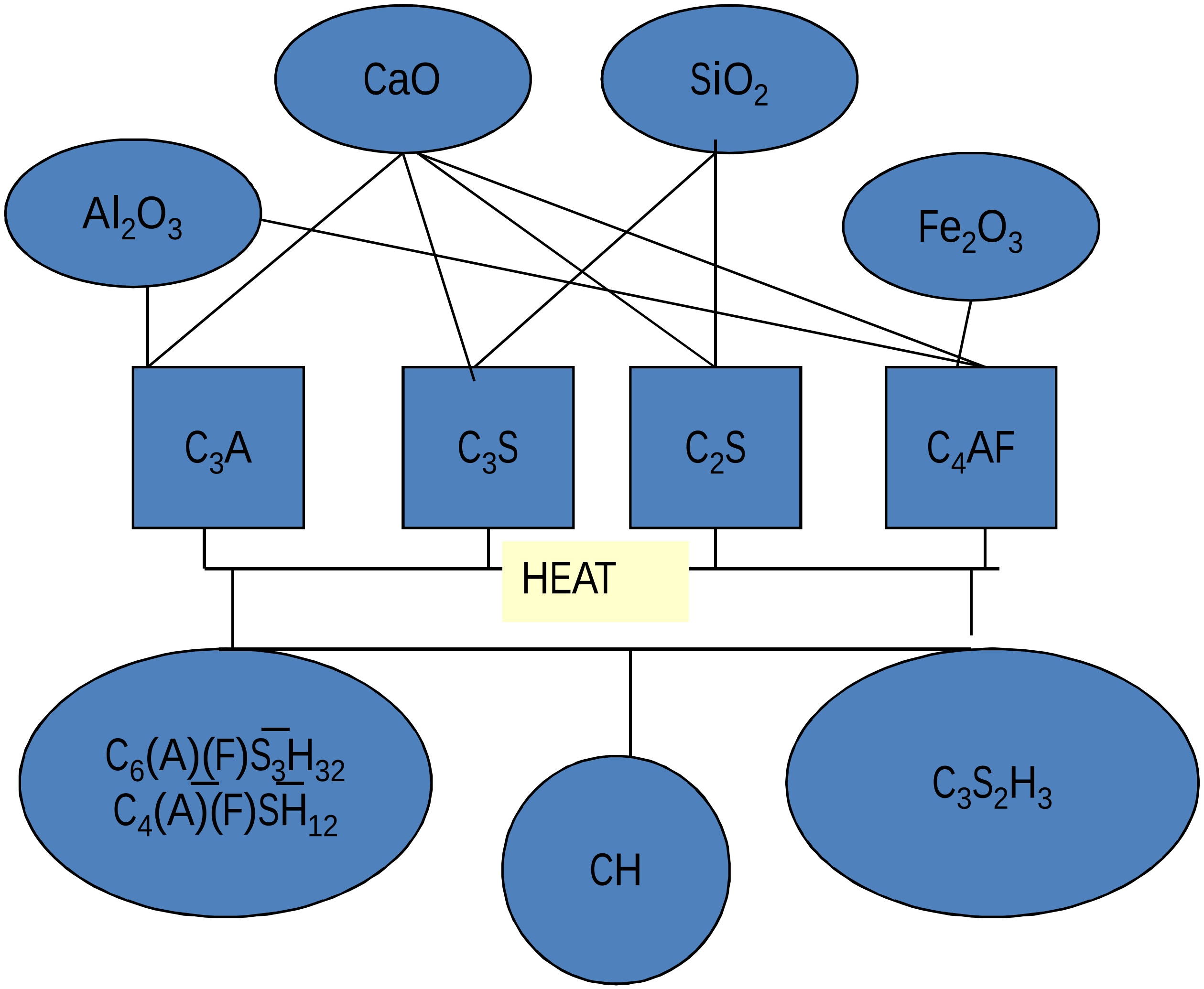
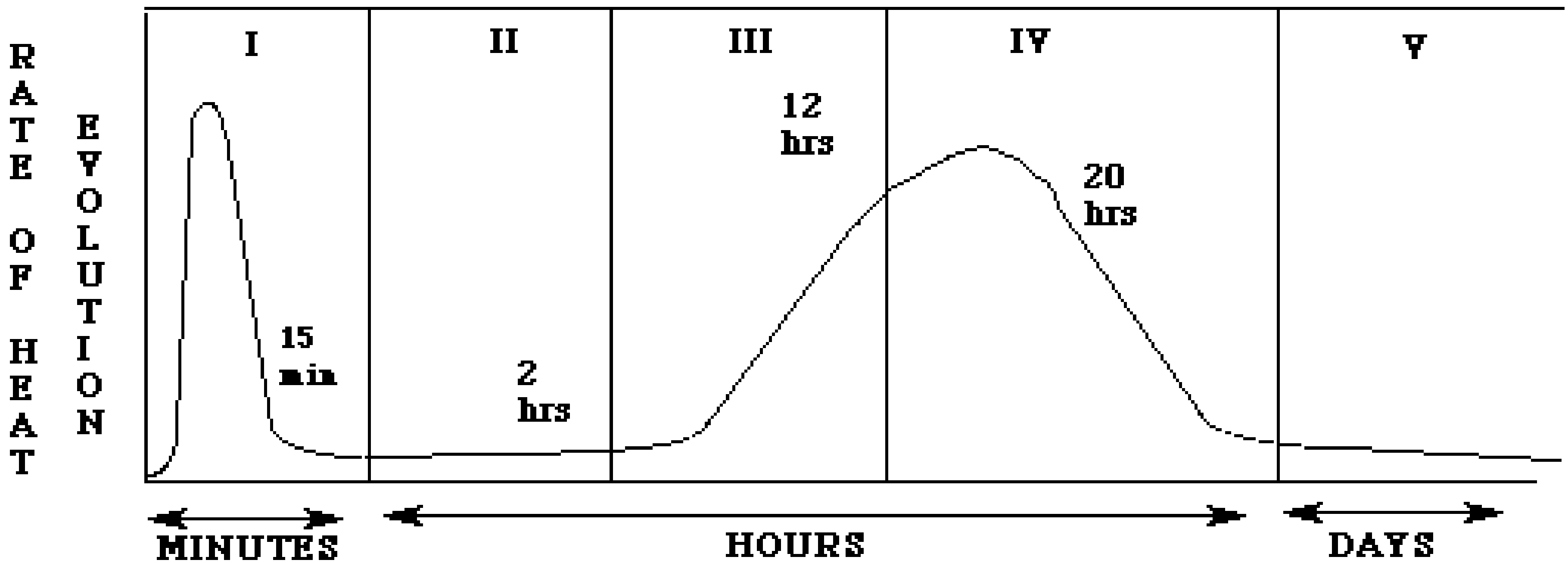
Metabolism of Cement (Chemistry)

Associative metabolism



Dissociative metabolism

Liberation of Heat during Hydration



Liberation of Heat is linked to chemical activity, this further affects hardening process. Please note the high exothermic activity at start, gypsum cooling and exothermic activity close to final setting.

Cement Hydration Compounds

- C_3S is responsible for early strength of concrete
- C_2S is responsible for later strength of concrete
- C-S-H gel makes up 50-60% of volume of solids in a completely hydrated cement paste. It determines the good properties of concrete
- $Ca(OH)_2$ is soluble in water and gets leached out making concrete porous, particularly in hydraulic structures

Water Requirements for Hydration

- 23% of water is required by weight of cement for chemical reaction with Portland cement compounds (bound water)
- Certain quantity of water is imbibed within gel-pores (gel-water)
- Bound water and Gel water compliment each other well
- 15% of water by weight of cement is required to fill up gel-pores
- Total 38% of water by weight of cement is required for complete chemical reactions and to occupy space within gel-pores

Types of Portland Cements

- Ordinary Portland Cements (OPC)
  - 33 Grade (IS 269)
  - 43 Grade (IS 8112)
  - 53 Grade (IS 12269)
- Special Cements
  - Rapid Hardening Portland Cement (IS 8041)
  - Low Heat Portland Cement (IS 12600)
  - Sulphate Resisting Cement (IS 12330)
  - Super Sulphated Cement (IS 6990)
  - White Cement (IS 8042)
- Blended Cements
  - Portland Slag Cement (IS 455)
  - Portland Pozzolana Cement (IS 1489)
  - Masonry Cement (IS 3466)
  - Earlier additive/blending was not permitted to clinkers except gypsum

BLENDED CEMENTS

A HOLISTIC APPROACH TO ENGINEERING

Permissible Blending Materials
(IS 456 – 2000)

- Fly Ash (Pulverized Fuel Ash) (IS 3812)
- Ground Granulated Blast furnace Slag (GGBS) (IS 12089)
- Natural pozzolana and volcanic ash (IS 3812)
- Silica Fume
- Meta-Kaoline
- Rice Husk Ash

The world wide trend now is to increase the use of pozzolana and cementitious materials in concrete

Methods of Blending

- "Blending" now replaces the term "additive". Hence, blended cements are those containing minerals as additive to OPC.
- Inter-grinding with cement clinker & gypsum.

  Suited for factory

  Blending OPC with powdered minerals.
- Suited at RMC or Cement productions manufacturing centres.
- Blending at on-site mixers
  - Low efficiency

Environment :Disposal of Waste ?

Supplementary Cementitious Materials

- Pulverized Fuel Ash
- Ground Granulated Blast Furnace Slag
- Silica Fume
- Rice husk Ash
- Natural pozzolana and volcanic ash *
- Meta-kaolin *

* *not a waste product*

Conclusion 1

BLENDED CEMENT is a better alternative to Ordinary Portland Cement as:

It gives better performance of concrete in terms of:

•STRENGTH,

•DURABILITY,

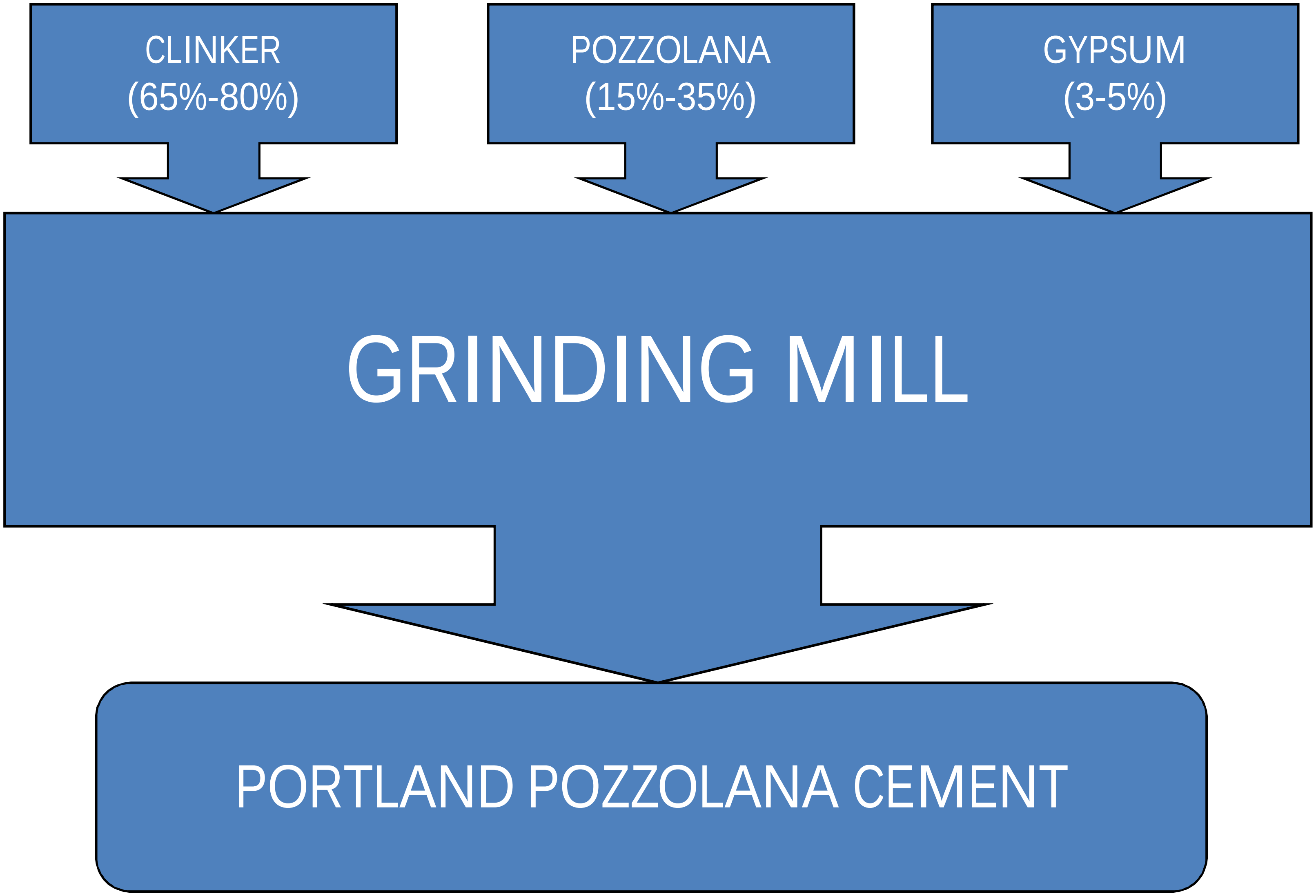
•FINISHING……; &

•ADDRESSES THE SOCIETAL OBLIGATIONS

IS 456-2000 Provisions

- Minimum cement 300 kg/m^3 includes OPC + blended materials
- Maximum 450 kg/m^3 Quantity of OPC not to exceed this limit.
- Blending material can be added to any quantity.
- Soil & Sub-soil water quality with respect to SO_3 & Cl_2, allows use of blended cements in most cases

PORTLAND POZZOLANA CEMENT



Potential in Gujarat is for……….PPC

Pozzolana

Essentially a siliceous or siliceous & aluminous material.

Natural form	Artificial form
clay & shale,	Fly ash
volcanic tuffs,	Rice husk
diatomaceous earth	

Fly Ash

Fly ash is a pozzolana, which is defined as fine material, which in itself is not cementitious but reacts with lime in the presence of water, under ambient conditions and forms hydrated mineralogy akin to that of OPC.

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Pozzolana - Fly ash

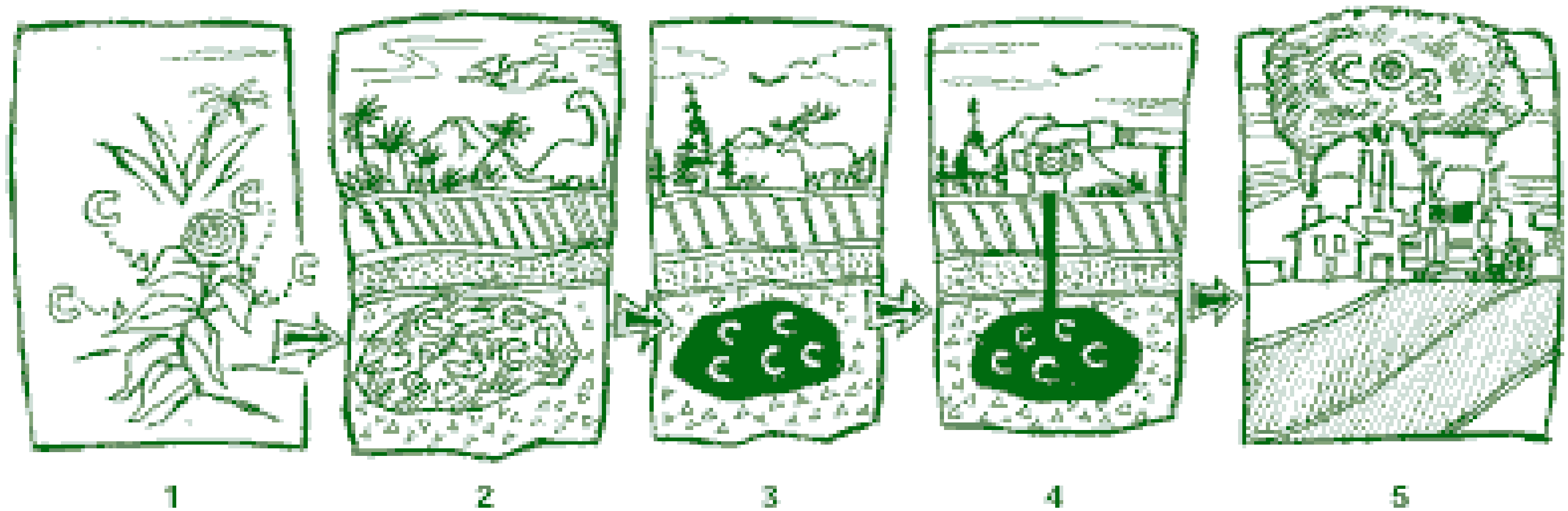
Fly ash: Commonly used in cement industry should have

- High lime reactivity
- Low carbon content
- High fineness

Fly ash is an engineering material and not a waste…

- *BIS CODE- IS:3812-1981*
- *Grade* – I- $(CaO+Al_2O_3+Fe_2O_3) > 70\%$
  - Low CaO- from Bituminous coal
- Grade-II- $(CaO+Al_2O_3+Fe_2O_3) > 50\%$
  - High CaO-from lignite coal

Fly ash origin



(1) Plants remove carbon dioxide from the air.
(2) When the plants died,they were buried in the earth.
(3) After millions of years,their remains turned into coal and oil.
(4) People mine the earth for coal and oil, which are called "fossil fuels."
(5) When people burn fossil fuels,they send carbon dioxide and other greenhouse gases into the air.

Fly ash is a by product from the combustion of fossil fuels

Importance of Fly Ash in Durable Concrete

- Fly ash generation in developed countries is less as electricity generation is by use of natural gas/ nuclear /other means. In India good quality of fly ash is abundantly available, which if used with cement as a partial supplement, produces durable concrete.

- At present it is estimated that about 36% of the electricity generated worldwide is Thermal while in India it is about 75 %.

Importance of Fly Ash In Durable Concrete

- For making higher grade concrete, Silica Fumes and Fly ash being used (products are results of combustion of coal)
- Fly Ash based cement not only safeguards against environment hazards but also improve quality of concrete structures in terms of durability
- Japan utilizes 94% of its fly ash for concrete compared to 10-15% in India. (growth seen in utilization over the past few years)

... contd

Importance of Fly Ash in Durable Concrete

- CO_2 emission can be minimized by using Fly Ash in cement concrete.

  Some Facts

  – Replacing 15% cement worldwide by SCM (Supplementary Cement Material (i.e. Fly Ash) will reduce CO_2 emission by 227 million tonnes

  – Replacing 50% of cement worldwide by SCM will reduce CO_2 by 750 million tonnes.

  – This is equal to removing 25% of all automobiles in the world.

Fly ash as Value Added Material for Concrete

- Good quality fly ash has mineralogical composition mainly consisting of Silica, Alumina, Iron Oxide and lime.
- Good quality fly ash consists of :
  - $SiO_2 + Al_2O_3 + Fe_2O_3$ - 75-80%
  - Silicon dioxide in Amorphous phase - 20% (min.)
  - Very fine particles of Silica of uniform consistency, mostly in spherical shape
  - Fineness nearly 3500 - 4000 blains (cm^2 / g)
  - Lime Reactivity > 5 MPa
  - Carbon Content < 2%

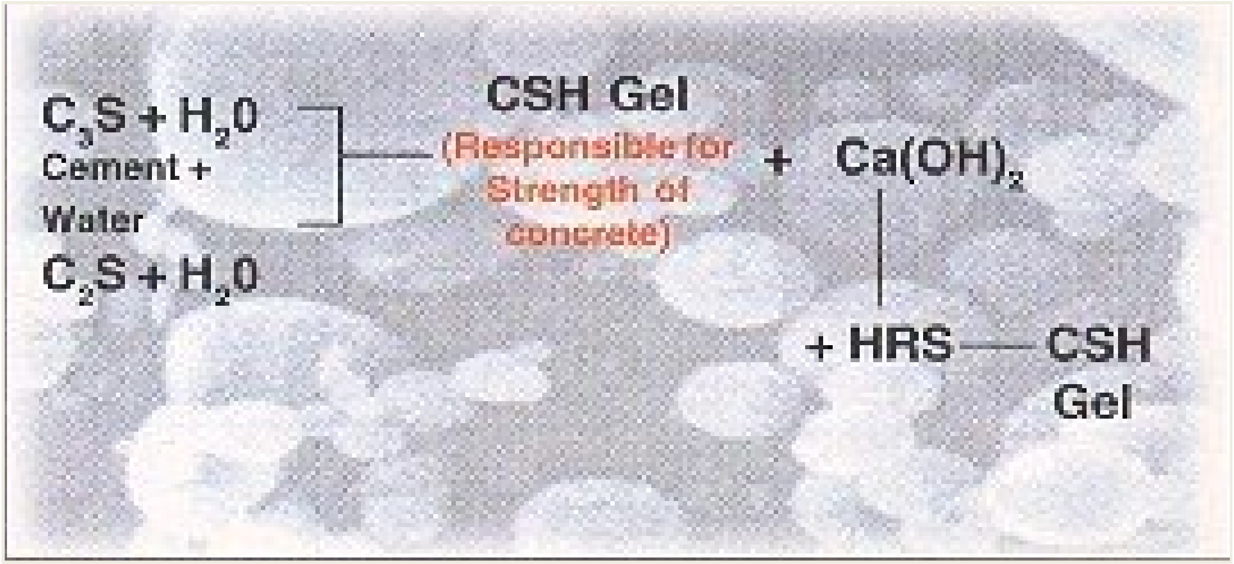
OPC and Fly ash – Synergy Effect: Fly ash is complimentary to OPC

Compound	OPC (%)	Flyash (%)
SiO_2	22	57
CaO	64	3
Al_2O_3	6	36
Fe_2O_3	4.5	5
MgO	1.00	0.50

Both show synergy in Chemical Composition

Reaction Mechanism

Reduction in Leaching



- Leaching in concrete reduces. Excess $Ca(OH)_2$ is consumed by HRS
- Increase in durability and strength over a period of time

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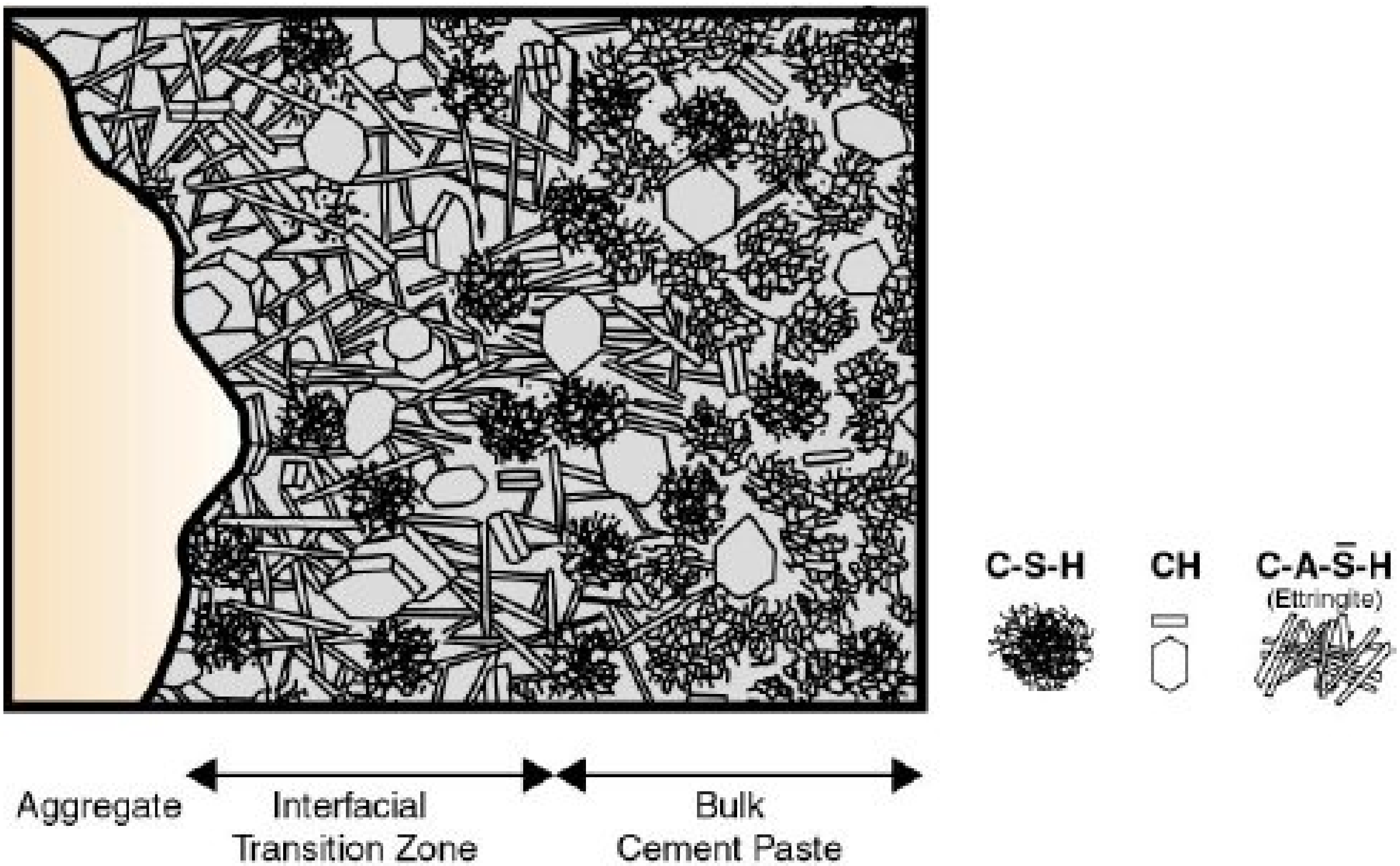
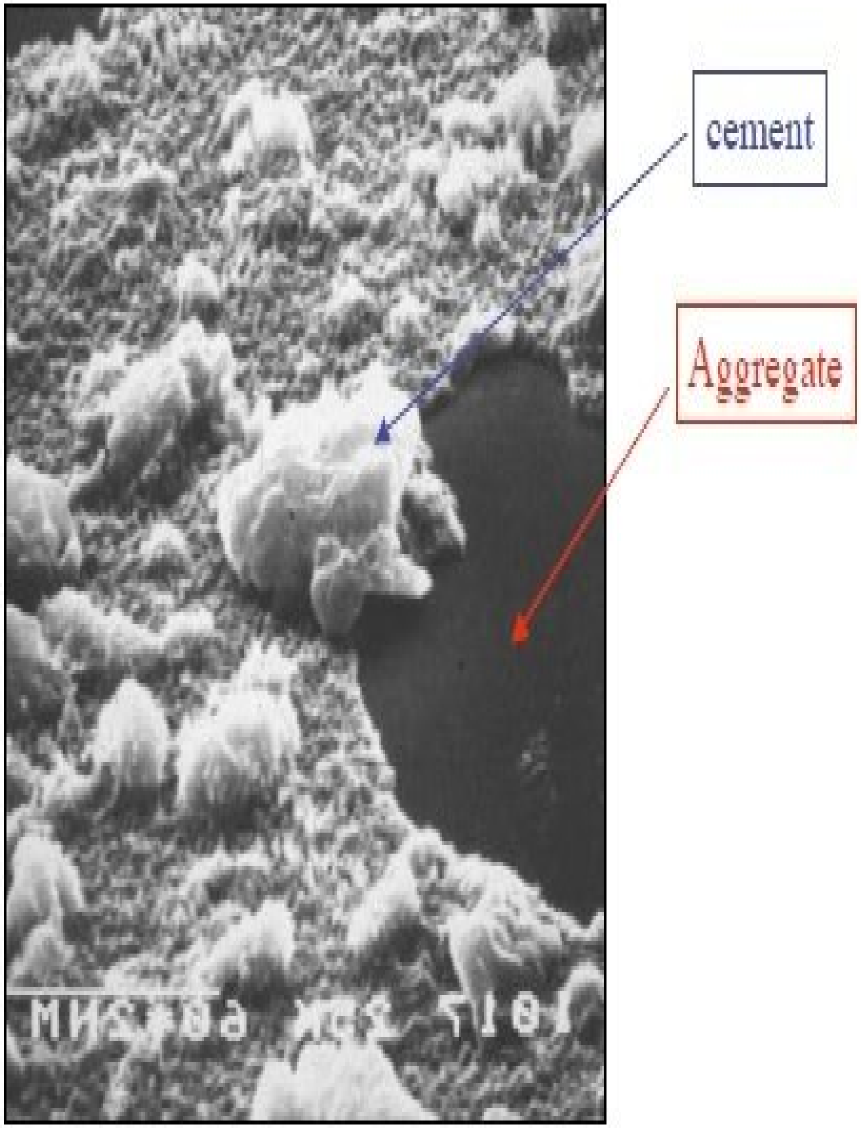
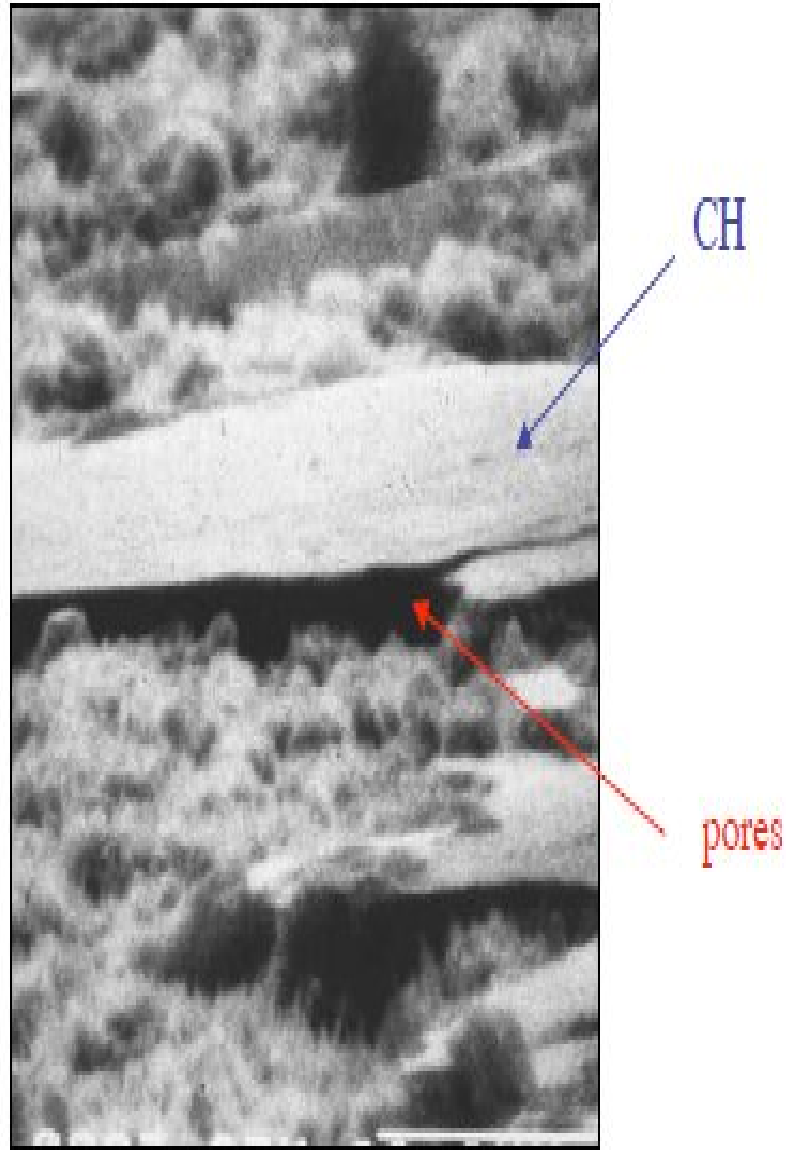
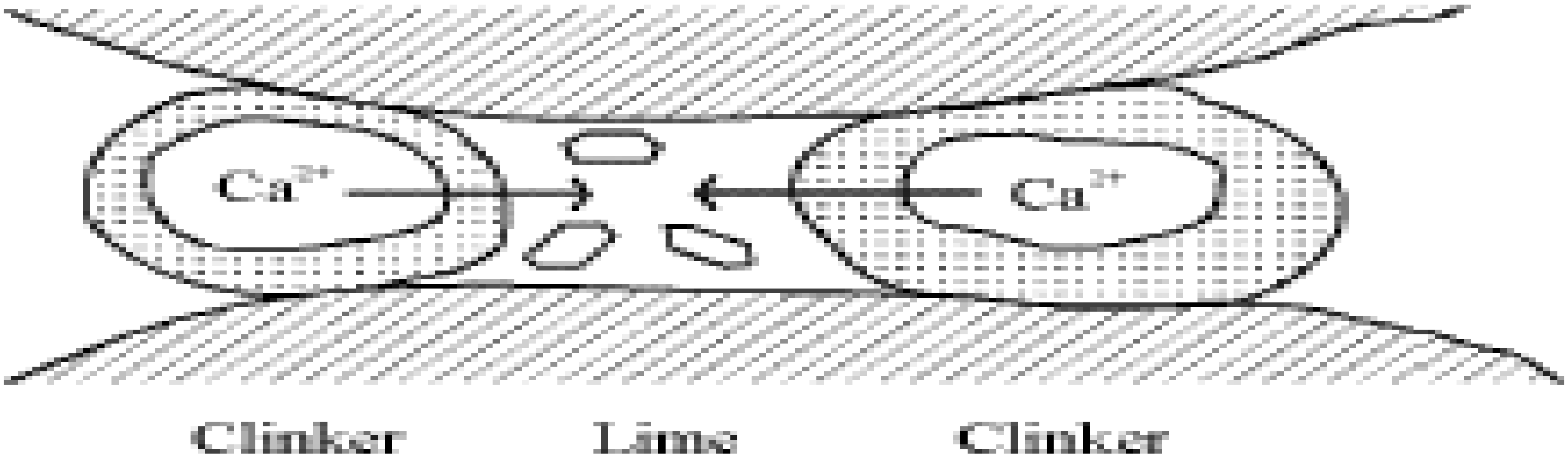
CSH Gel (Graphic display)

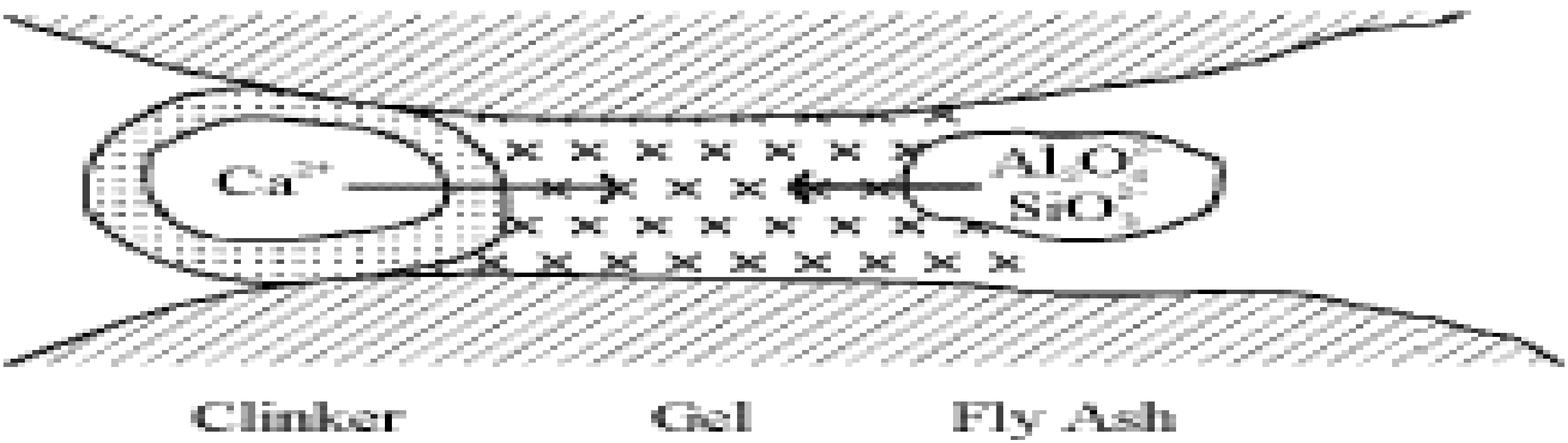



cement
Aggregate


CH
pores



: 7: The pore filling of Portland cement concrete



: 9: The pore filling of fly ash cement concrete

Pozzolanic Reaction: Benefits

- Continued hydration
  - Higher long term strength
  - Reduced heat of hydration
  - Improved resistance to chemical attack
- Reduced Water demand (7.5-9.4%)
  - Reduced bleeding
  - Reduction in shrinkage and creep
  - Lower permeability
- Improved Cohesion
  - Less segregation
  - Less difficulties in concrete placement

Pozzolana- Benefits

- Presence of very fine pozzolana results into following:
  - Cohesive & workable concrete
  - Superior finish
  - Less evaporation of water

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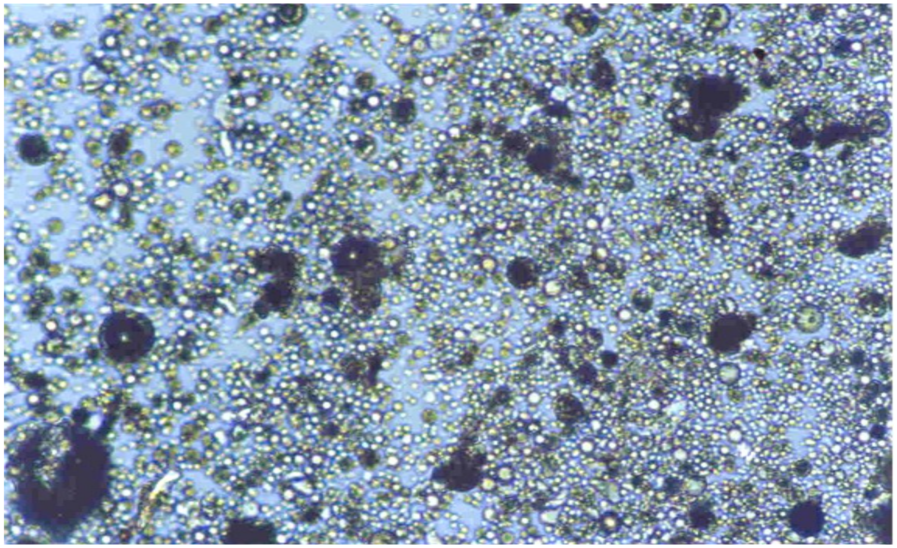
Chemistry of Fly ash

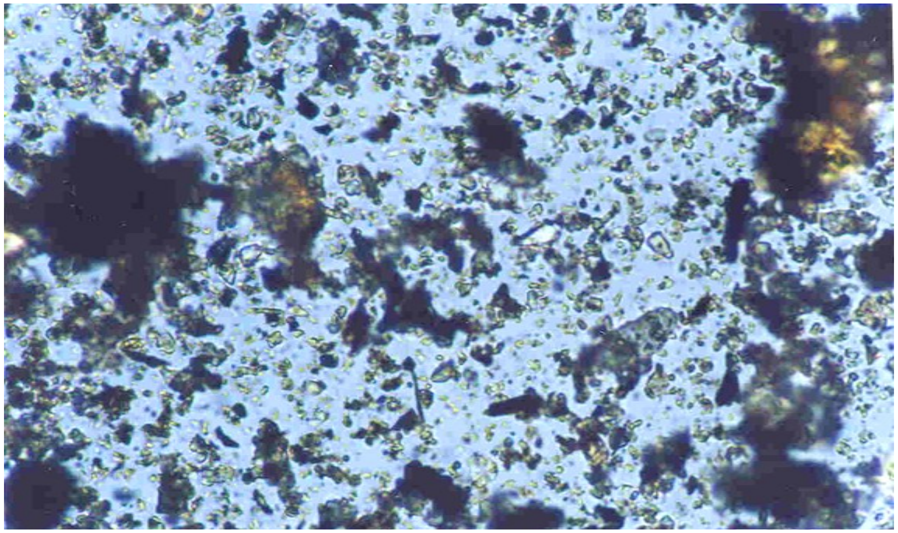
Sno	Test	Unit	IS 3812
1	$SiO_2+Al_2O_3+Fe_2O_3$	%	70 min
2	SiO_2	%	20 min
3	Reactive silica	%	20 min
4	MgO	%	3 max
5	SO_3	%	3 Max
6	Na_2O	%	1.5 max
7	Total Chlorides	%	0.05 Max

HATHI CEMENT

Sno	Physical Test	Unit	IS 3812
1	Fineness (Blaines Permeability test)	m2/kg	320
2	Resiude on screen 45 microns	%	34
3	Loss on Ignition (Max)	%	5
4	Water requirment	%	115
5	Lime Reactivity	N/cm2	4.5
6	Moisture conternt (Max)	%	2
7	Soundness (Autoclave)		0.80%
8	28 day comp st - plain mortar cemnet	N/ mm2	80%

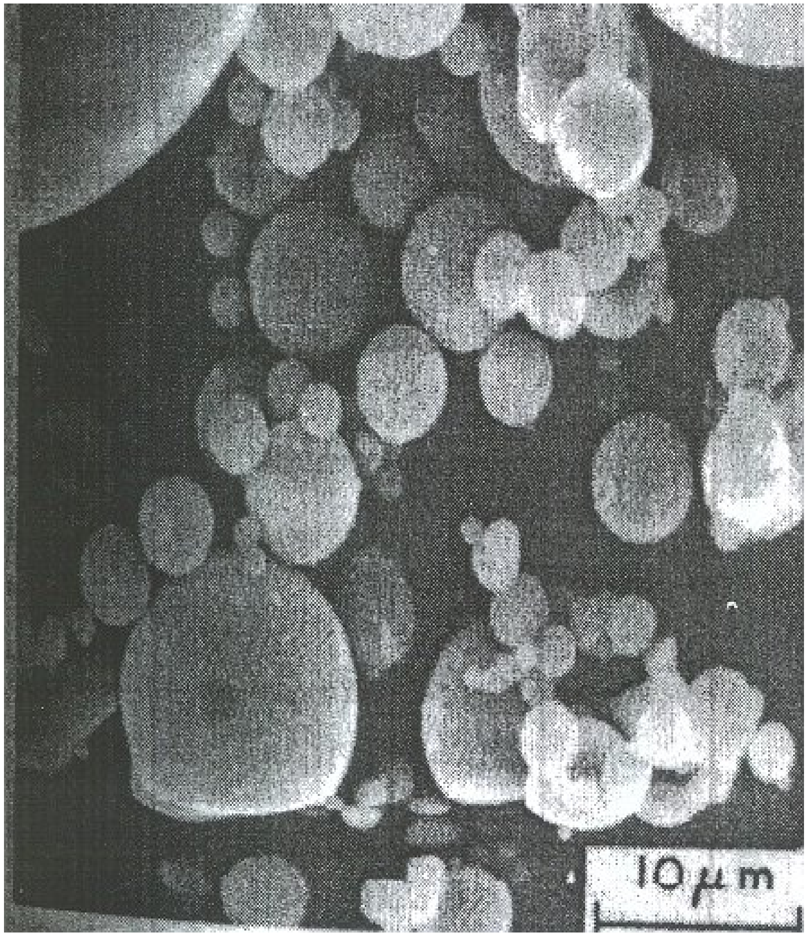


Good Quality Flyash (HRS)

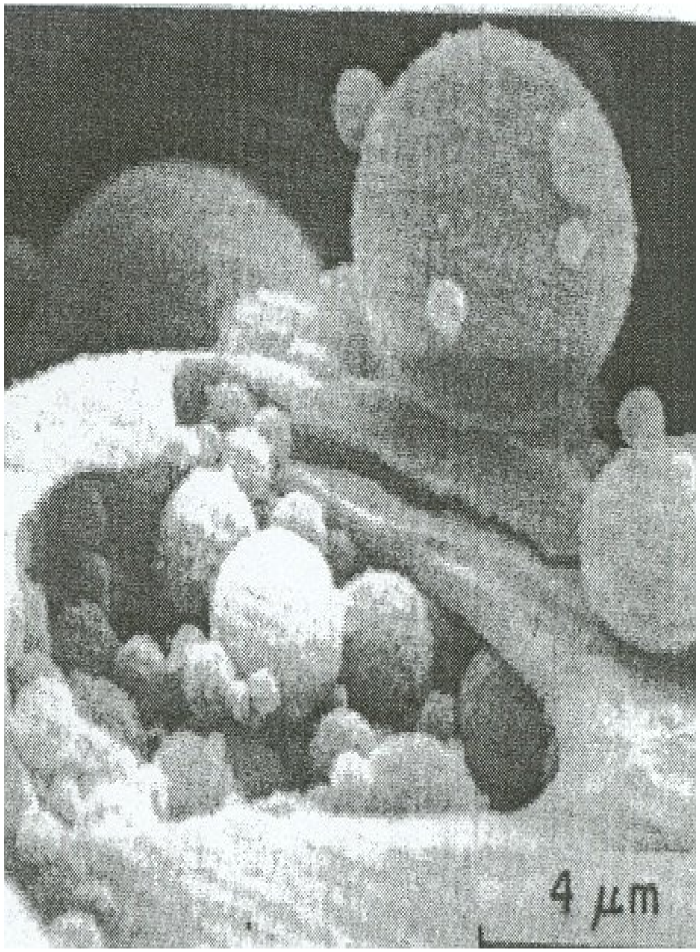


Ordinary Flyash

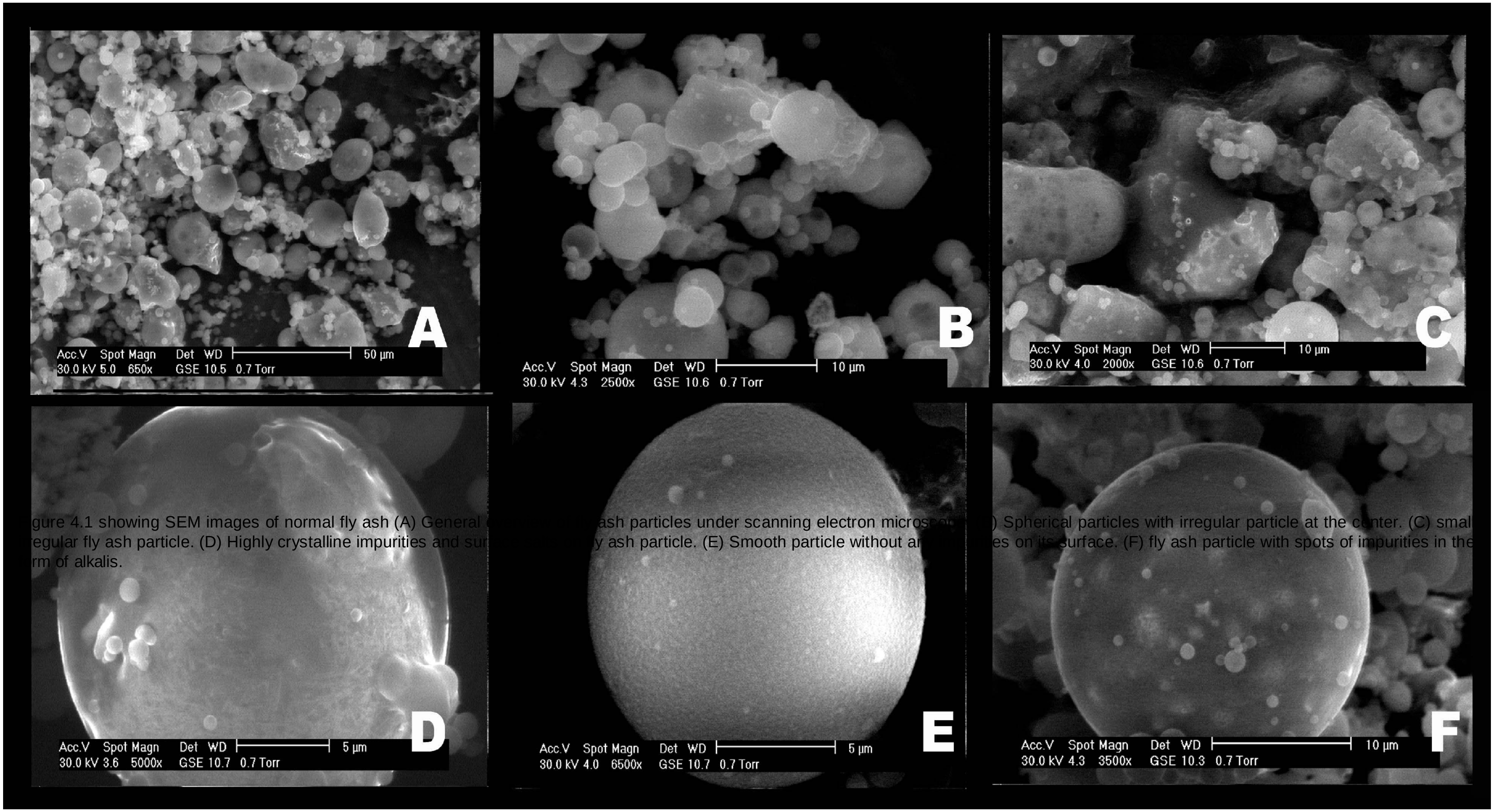
Electron micrographs of a Typical Fly Ash



Spherical and Glassy particles



A Plerosphere



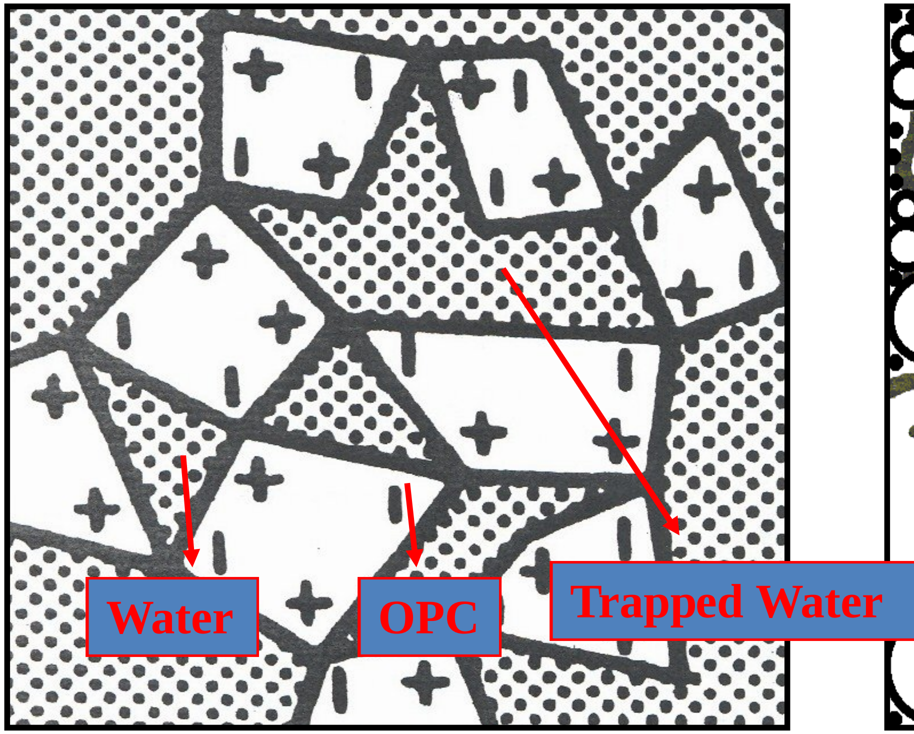
SEM images of normal fly ash

(A) General overview of fly ash particles under scanning electron microscope.
(B) Spherical particles with irregular particle at the center.
(C) Small irregular fly ash particle.
(D) Highly crystalline impurities and surface salts on fly ash particle.
(E) Smooth particle without any impurities on its surface.
(F) fly ash particle with spots of impurities in the form of alkalis.

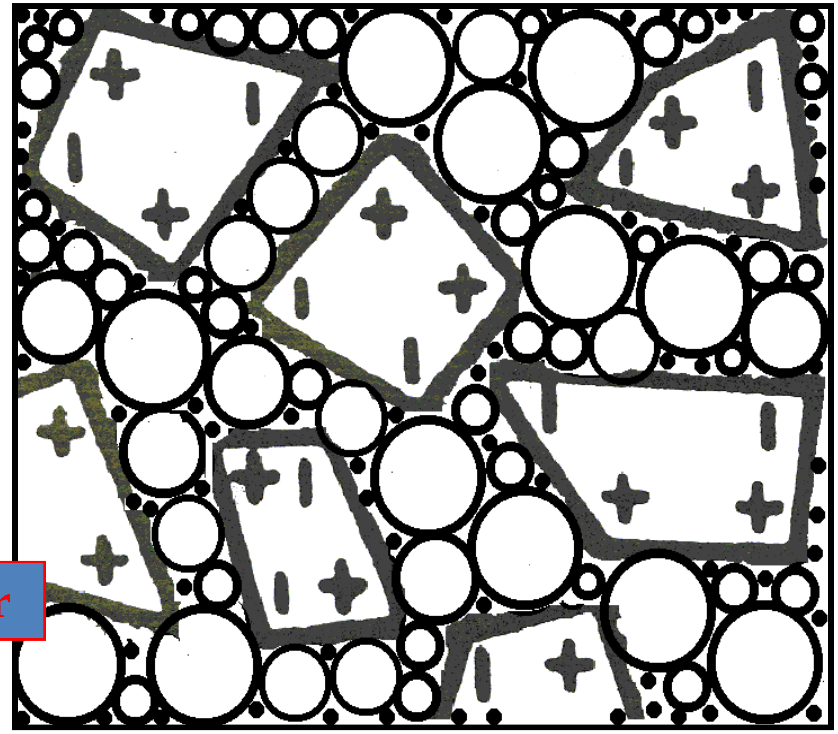
Mechanisms by which Fly ash (HRS) Improves Properties of Concrete

- Dispersion of cement particles
- Availability of larger surface area for hydration.
- Reduction in amount of trapped water between cement particles
- Particle Packing effect
  - ❖ Reduction in voids – HRS is more efficient void filler than OPC
  - ❖ Reduced water requirement to achieve a given consistency
- Ball Bearing effect
  - ❖ Spherical shape reduces inter-particle friction.
  - ❖ Facilitates mobility of mix and improves its rheology

Dispersion of Cement Particles

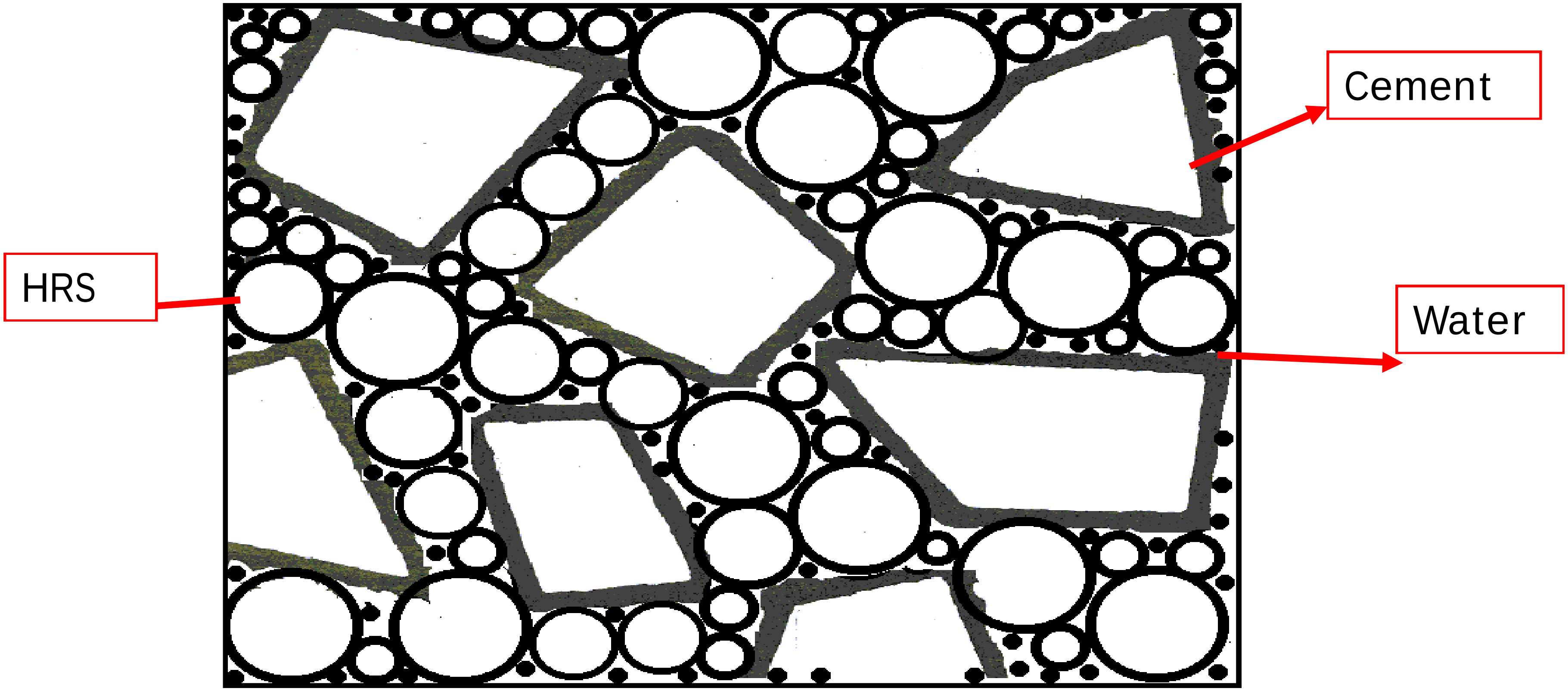


Presence of electronic charges, on Portland cement particle surface, tend to form flocks that trap large volumes of water



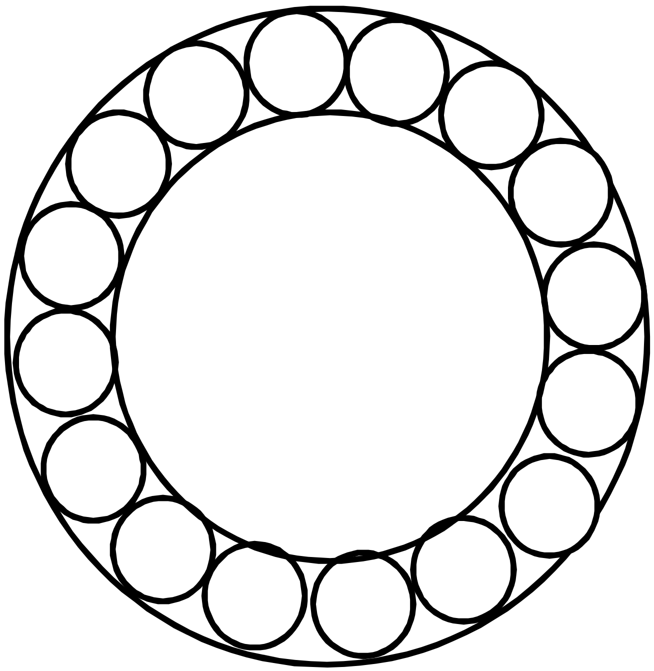
"Dispersion of Cement Particles" - Fine HRS particles get adsorbed on the oppositely charged surface of the cement particles and prevent them from flocculation

Particle Packing Effect

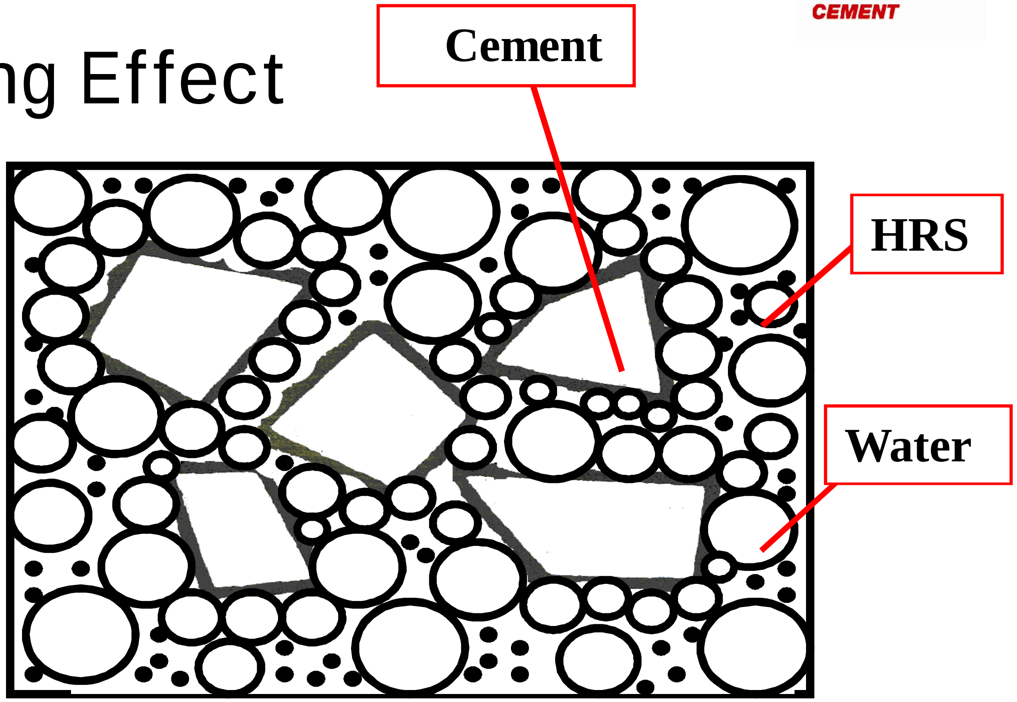


- HRS improves density of mix by filling voids.
- Water has lowest density, out of all constituents
- Replacement of water by HRS densifies mix

Ball Bearing Effect



Typical Ball Bearing



Reduction in inter-affinity between OPC particles due to Ball Bearing Effect provided by HRS

- Create lubricating action when concrete is in plastic stage
- Spherical shape & smooth surface of HRS helps reduce inter-particle friction.
- HRS particles plasticize cement paste and improve flow-ability and rheology

Specifications v/s Test Results

Particulars	IS12269 OPC 53 Grade	IS:1489 PPC	PPC available
Fineness(m2/kg)	225	300	353
IST minimum (minutes)	30	30	190
FST maximum (minutes)	600	600	270
3 day Comp. Strength MPa	27	16	33
7 day Comp. Strength MPa	37	22	45
28 day Comp. Strength MPa	53	33	61

Benefits of PPC in Concrete

Fresh Concrete

- Reduces water demand
- Increases workability
- Improves rheology of mix
- Enhances water retention
- Increases cohesiveness & pump-ability
- Reduces internal bleeding and segregation
- Reduces plastic shrinkage
- Better slump retention
- Reduces danger to honeycombing
- Better surface finish

Effect of Addition of Fly Ash

Hardened Concrete

- Converts $Ca(OH)_2$ to C-S-H Gel
- Contributes to long term strength
- Enhanced uniformity and homogeneity
- Reduces permeability of concrete
- Reduced volume changes
- Enhanced cover quality
- Increases durability

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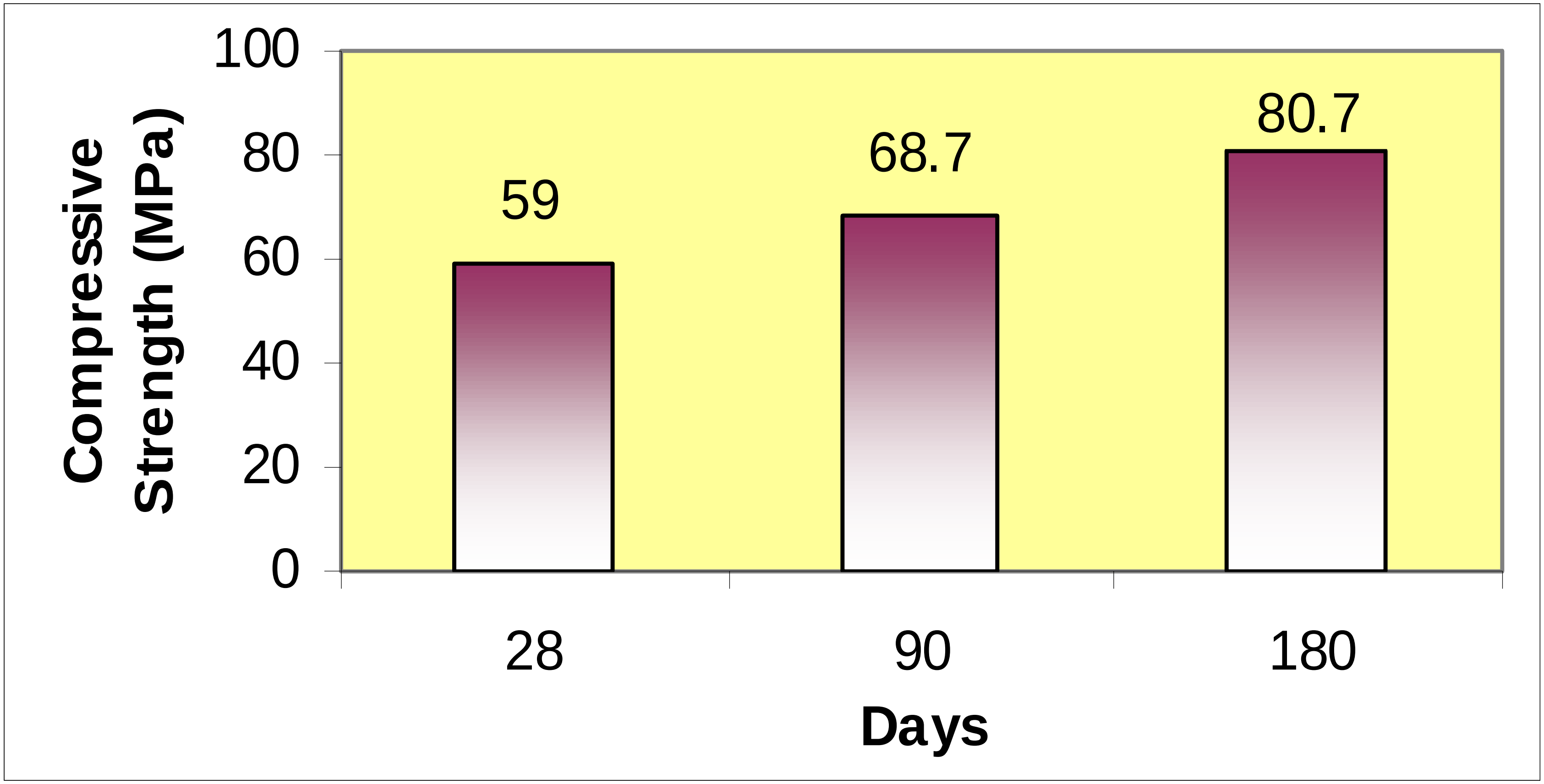
Advantage 1: Long Term Strength Gain



Increase in strength at 180 days is 36% higher than at 28 days

Advantage 2: Hardened concrete

- Steady strength gain & enhanced long term strength
- Improved transition zone
- Low porosity and discontinuous pores system, better impermeability
- Resistance against chemical attacks
- Reduced carbonation

Advantage 3: Medium Resistance to Sulphates

- Low C_3A in PPC makes it moderate sulphate resisting cement
- IS 456:2000 specifies C_3A between 5-8% to resist chloride and sulphate attack

Scope of PPC in Construction Industry

- Availability of superior blended cements
- High level of sulphate & chloride found in sub-soil and ground water in the coastal belt of Gujarat
- Increasing air pollution - carbonation
- Extreme weather condition
- Recognition of its benefits through codal provisions
- Rising expectations from concrete- High Performance Concrete

Fly ash in concrete: Sites in India

- Gujarat State Highway Projects
- Sardar Sarovar Narmada Nigam Dam Project & Other Dam Projects
- Fly-overs & Bridges
- Bandra-Worli Sea Link Project
- Delhi Metro Rail Project
- Rajasthan Atomic Power Project
- Kaiga Atomic Power Station

Application of PPC

- Dams
  - For high volume concreting work
  - Increase durability
  - Resistance to thermal cracking

- Power
  - o Concrete in foundations, floors and roofs
  - o improved workability

Application of PPC

- Harsh environments & Marine applications
  - Tunnel-Linings
  - Treatment plants and sewage works
  - Docks, Jetties
- Concrete Roads

Many marine structures in the Netherlands have been built with blended cements

Good Practices: Concrete using PPC

- Ample water
- Do not let it dry
- Dry concrete = dead concrete, all reactions stop
- Can not revitalize concrete after it dries
- Keep temperature at a moderate level
- Concrete with PPC requires continuous and consistently good quality curing

Good Practices: Stripping of Formwork

Type of Formwork	*Minimum Period Before Striking Formwork*
a) Vertical formwork to columns, walls, beams	16-24 h
b) Soffit formwork to slabs (Props to be refixed immediately after removal of formwork)	3 days
c) Soffit formwork to beams (Props to be refixed immediately after removal of formwork)	7 days
d) Props to slabs:	
1) Spanning up to 4.5 m	7 days
2) Spanning over 4.5 m	14 days
e) Props to beams and arches:	
1) Spanning up to 6 m	14 days
2) Spanning over 6 m	21 days

HATHI CEMENT

Sample Mix Design – PPC blended @ 20% Fly ash: (NPC)

Details	Mix 1		Mix 2		Mix 3	
Types of Cement	OPC	PPC	OPC	PPC	OPC	PPC
Cement Content (kg)	350	350	400	400	450	450
W/C	0.45	0.45	0.40	0.40	0.35	0.35
S/C	2.55	2.54	2.09	2.80	1.73	1.72
A/C	3.01	2.99	2.67	2.65	2.40	2.38
Admixture(%)	1.25	1.5	1.25	1.25	1.25	1.25
Slump (mm) 0 min	210	220	220	190	210	210
30 min	130	180	200	90	190	160
Compressive Strength (Mpa)						
7 Days	30.8	26.6	40.9	35.0	43.1	30.4
28 Days	42.3	43.2	48.3	49.6	57.8	55.1
56 Days	48.2	52.8	50.6	61.8	60.6	64.3
Split Tensile (Mpa)						
28 Days	3.60	3.89	4.13	3.72	4.03	3.87

Conclusion 1

Balanced Chemical Properties of Blended Cements: Facilitates Durable Construction. Chemically is backed by:

- Low chloride
- Low magnesia
- Low alkali
- Low impurities / insoluble residue
- Optimum C_3S
- Moderate C_3A

Conclusion 2: ADVANTAGE +

FEATURES : ADDS VALUE TO 53 GRADE ORDINARY PORTLAND CEMENT

A. MAINTAINS OPC 53

- STRENGTH
- SETTING TIME
- SOUNDNESS

B. ADDS ON ADVANTAGES

- DENSER GEL FORMATION
- LOW HEAT OF HYDRATION
- RESISTANCE TO CHEMICAL ATTACKS
- RESISTS INGRESS OF MOISTURE
- MINIMIZES CRACKS
- REDUCES LEACHING

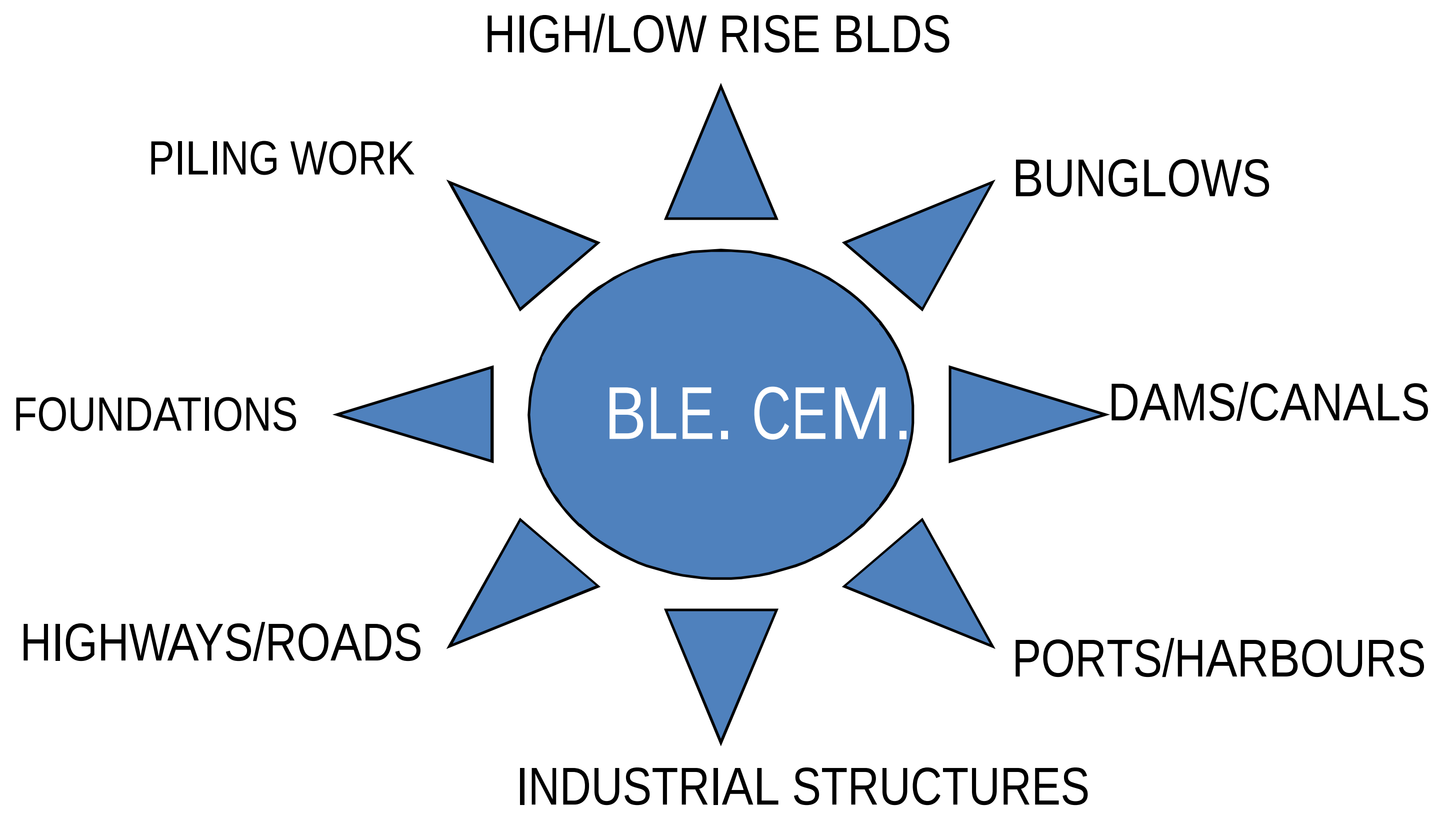
HATHI CEMENT

Conclusion 3

MYTHS	REALITIES
SLOW SETTING	CAN BE REGULATED
INFERIOR THAN OPC	BETTER THAN OPC
NOT POPULAR	NARROW PERSPECTIVE
NOT TO BE USED IN RCC	BETTER IN RCC
CHANGE IN CONST.METHODOLOGY	NO

HATHI CEMENT

Conclusion 4: APPLICATION SPECTRUM for PPC



ANY STRUCTURE-BIG OR SMALL

Conclusion 5

- Blended Cements enhance Durability: i.e. enhance performance of concrete in aggressive environments
- Good quality Blended Cement is available, which is superior to OPC 53
- Adopting Blended Cements is not a preference but a compulsion

THANK YOU*

* Document prepared with inputs from Prof Urmil Dave, Nirma University