Increased utilization of Fly Ash for High Performance GREEN Concrete

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Presented for DIRK Phoenix Pvt Ltd at

FLY ASH Utilization 2019 Goa

1942 born next
an ash lagoon
Germany

This presentation deals with low lime Class F fly ashes, which according to ASTM C 618 have a CaO content less than 10%. I will briefly describes the benefits that can be imparted to the performance of concrete by using processed fly ash and how this performance of concrete can be further enhanced with increasing fineness of fly ash, in three aspects:

……namely in its **(i) fresh state**: mainly workability, stability and mperature rise, **(ii) hardened state:** mainly compressive strength and e associated engineering properties such as tensile strength and odulus of elasticity (**iii) durability:** mainly permeation properties and sistance to chloride ingress and therefore corrosion of steel inforcement, sulfate attack and alkali – silica reaction.

vill then describe the developments of a range of fly ash products, in articular those making use of fine and ultrafine fly ashes to increase e fly ash content in blended High Performance Pozzolan Cements to arply increase the beneficial use of Fly Ash.

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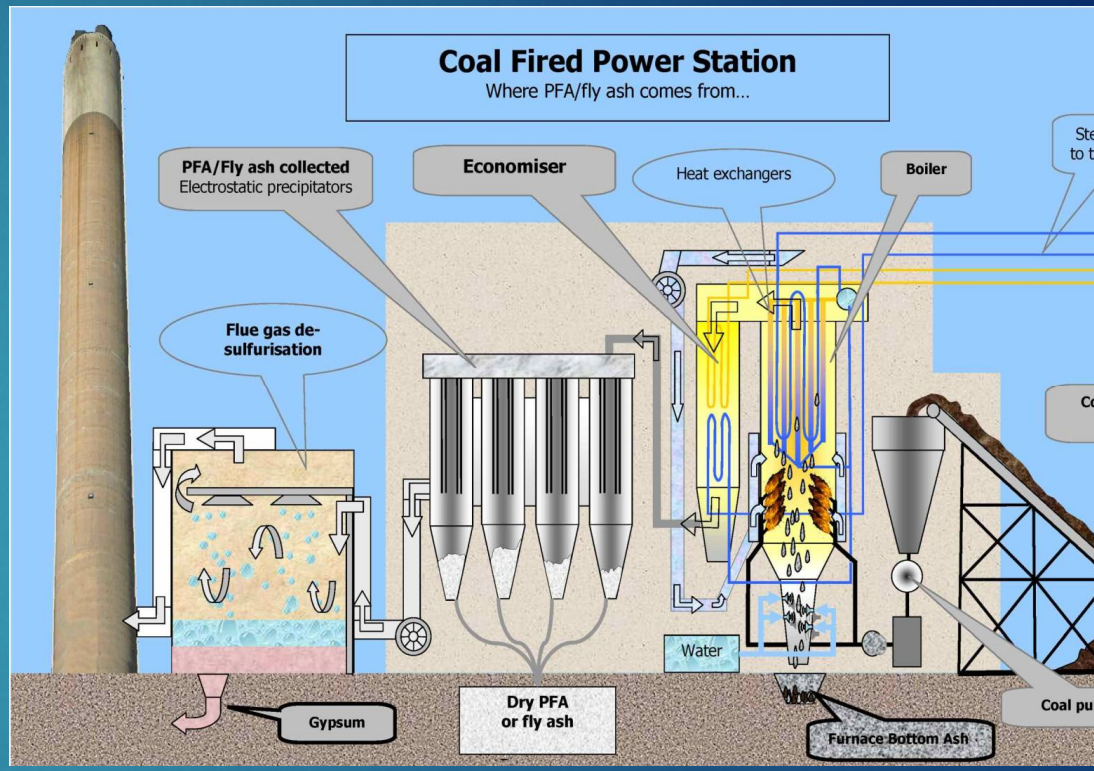
ash is a by-product of the
nbustion of pulverized coal in
rmal power plants.
dust collection system (Electronic
cipitators) removes the fly ash as a
particulate residue, from the
nbustion gases.
ash particles are typically spherical
meter ranging from less than 1µm up
50 µm.



Fly Ash generated in coal fired power stations is a Pozzolana. A pozzolana is defined as "a silicious or aluminous material which itself possess little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with Calcium hydroxide, at ordinary temperature to form Compounds possessing cementitious properties."

Fly ash improves the Properties of Concrete

Improvement will be through
Purely Physical effects associated with the presence of very fine particles.

Physical – chemical effects associated with pozzolanic reactions that results in pore – size reduction and grain – size reduction phenomena.

The currently major beneficial use of Fly Ash (approx. 50%) is as partial replacement of Ordinary Portland Cement (OPC)

Although coal combustion is in a number of states in decline, there is overall a wide gap between Fly Ash generation and beneficial use of Fly Ash.

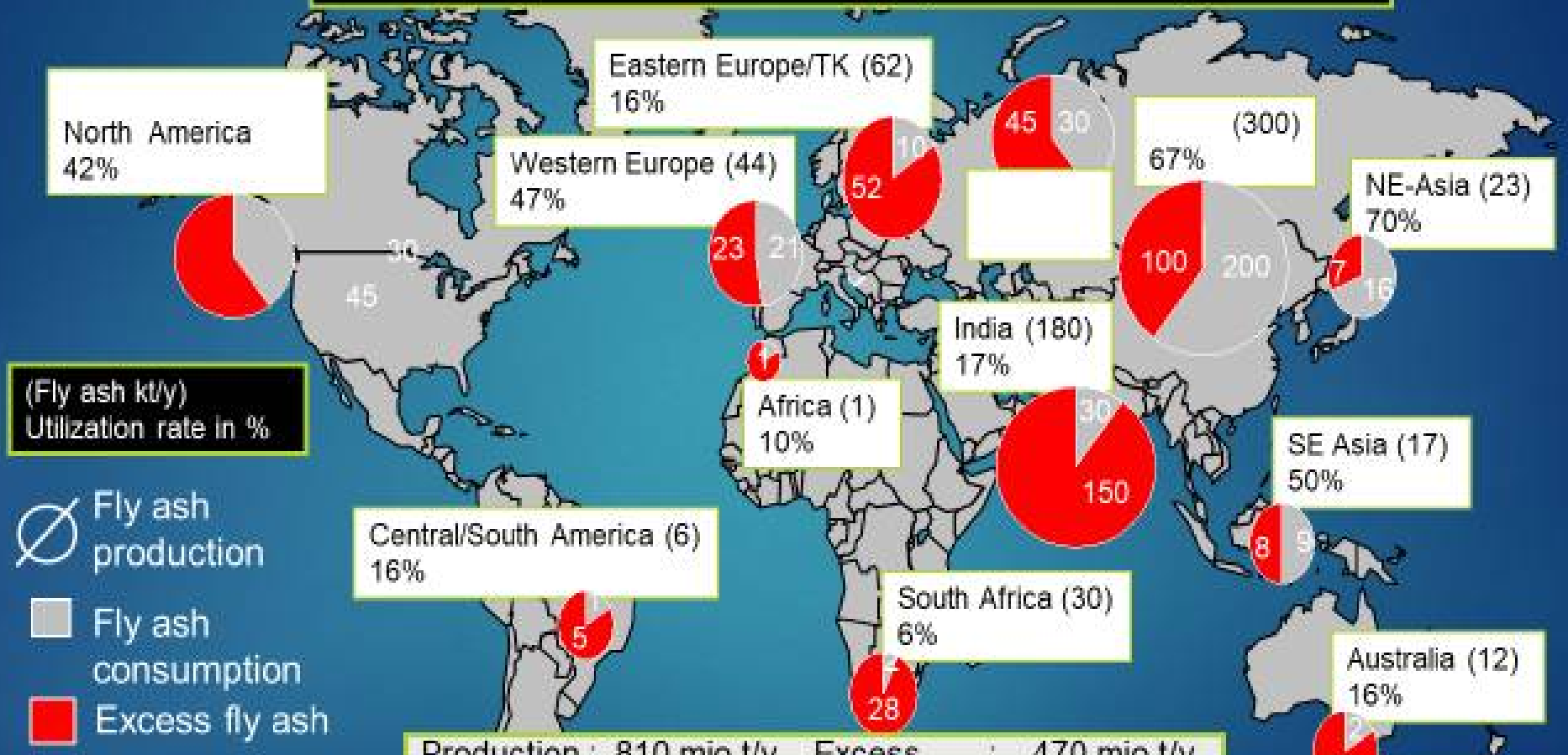
IF NOT UTILIZED FLY ASH REMAINS WASTE

.

Occupying arable land, consuming vast amounts of water if wet disposed, creating dust pollution, damaging public health and incurring substantial disposal cost

Global fly ash production/utilization 2010 (mio t/y)

Excess volumes limited due to quality and availability contraints



Production :	810 mio t/y	Excess :	470 mio t/y
Utilization :	340 mio t/y	Pot. Usable:	230 mio t/y
Utiliz. rate :	42 %	Non usable:	240 mio t/y

Source: HOLCIM

HGR5_Master

The Indian scenario : from where to start the increase of utilization

Fly Ash generated in 2017 = 169 million metric tons
Fly Ash utilized in 2017 = 107 million metric tons
Fly Ash utilization as percentage = 68%

This increase was partly achieved by the **Cement industry determined to produce PPC**, the **Ready Mix Industry to use Fly Ash for blending with OPC** and the Power generator being forced **to subsidise Fly Ash transport** for up to 300 km distance to utilisation sites and the Government providing **reduces tax rates**.

Problem Ash factor:
Coal consumption = 509 million metric tons
Total installed capacity = 157 GW
Average ash factor of washed and unwashed coal = 30 %

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Fly Ash as a waste….a typical Fly Ash lagoon

Only one typical case where mere 1000 MT of Fly Ash per day are sent to wet disposal: (there are more than 100 of such sites in India)

Clip from the Dirk India video: Can we afford this?

Taking the problem head on.... 1st. Fly Ash seminar Mumbai 2001

More than 500 participants from all over India attended.

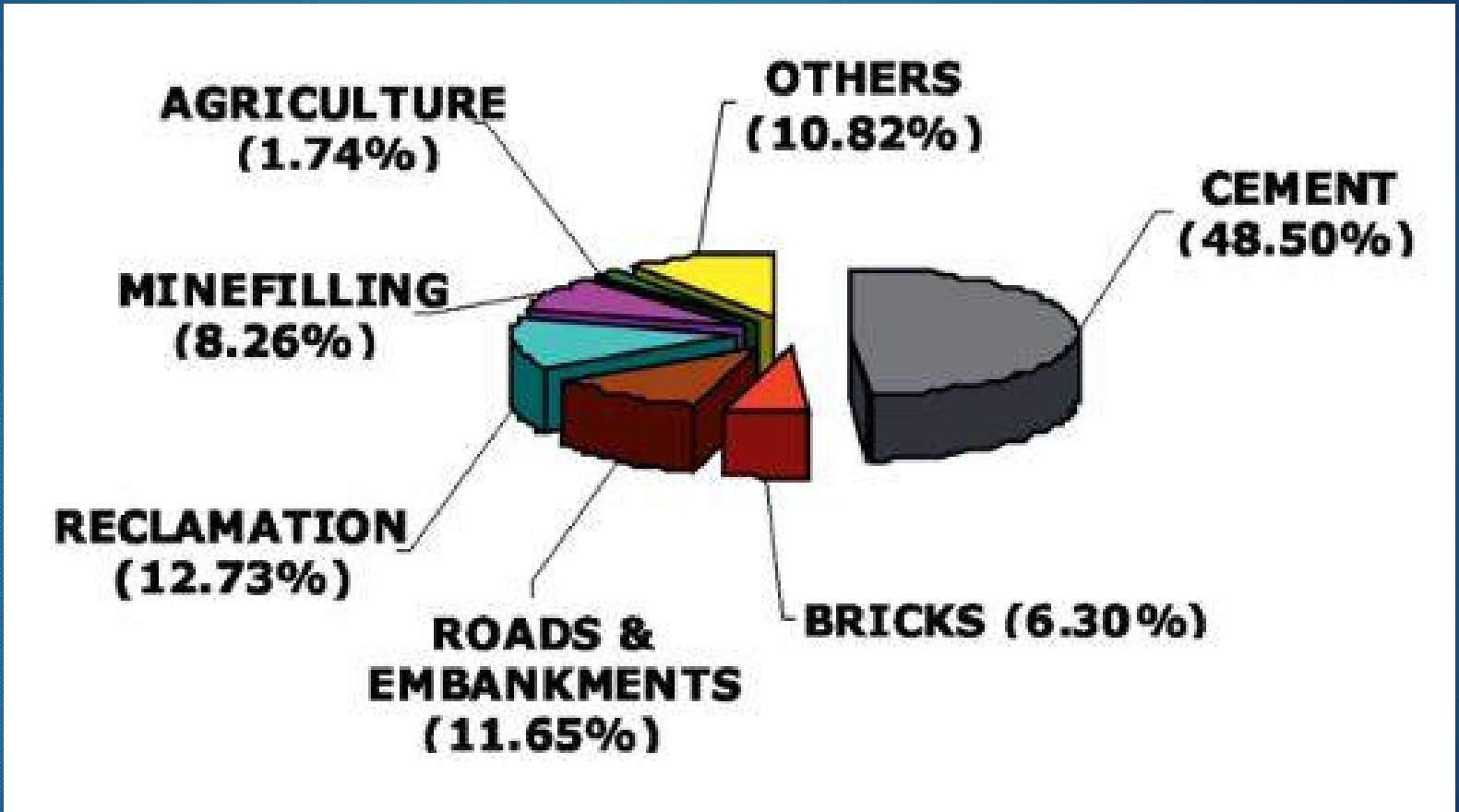
From right to left:

Dr. Vimal Kumar (Fly Ash Mission India, Mr. Ravendra Darda (State Minister of Power, Maharashtra, Georg Dirk (host), B Penny Wensley British High Commissioner for India, Dr. Parminder Singh (Power Minister , Maharashtra), Mr. Peter Wilkinson Director of Operations (Dirk European Holdings Ltd. UK)

Taking the problem head on... technology dissemination

40 x 20 feet

neficial Fly Ash utilization in India after years of technical semination and practical on site demonstrations



Development of Fly Ash generation vs utilization in India

emination shows
ults

S. No.	Year	Fly-ash Generation (Million tons per annum)	Fly-ash utilization (Million tons per annum)	% Utilization
1	1996-97	68.88	6.64	9.63
2	1997-98	78.06	8.43	10.80
3	1998-99	78.99	9.22	11.68
4	1999-2000	74.03	8.91	12.03
5	2000-01	86.29	13.54	15.70
6	2001-02	82.81	15.57	18.80
7	2002-03	91.65	20.79	22.68
8	2003-04	96.28	28.29	29.39
9	2004-05	98.57	37.49	38.04
10	2005-06	98.97	45.22	45.69
11	2006-07	108.15	55.01	50.86
12	2007-08	116.94	61.98	53.00
13	2008-09	116.69	66.64	57.11
14	2009-10	123.54	77.33	62.60
15	2010-11	131.09	73.13	55.79

Consumption in Cement production is due to grow…….but will not solve the problem

Table 4- Expected Fly-ash absorption in cement (million tons per annum) (Source: WBCSD/CSI/LOW Carbon technology road map for Indian cement industry)

Serial No.	Year		Expected Fly-ash absorption in Indian Cement Industry (million tons per annum)
1	2015	EXPECTED ANNUA L. PFA PRODUCTION	52.65
2	2020		73.01
3	2025	300 m / MT	94.63
4	2030		120.50
5	2035		143.72
6	2040		158.02
7	2045	900 m / MT	167.74
8	2050		177.45

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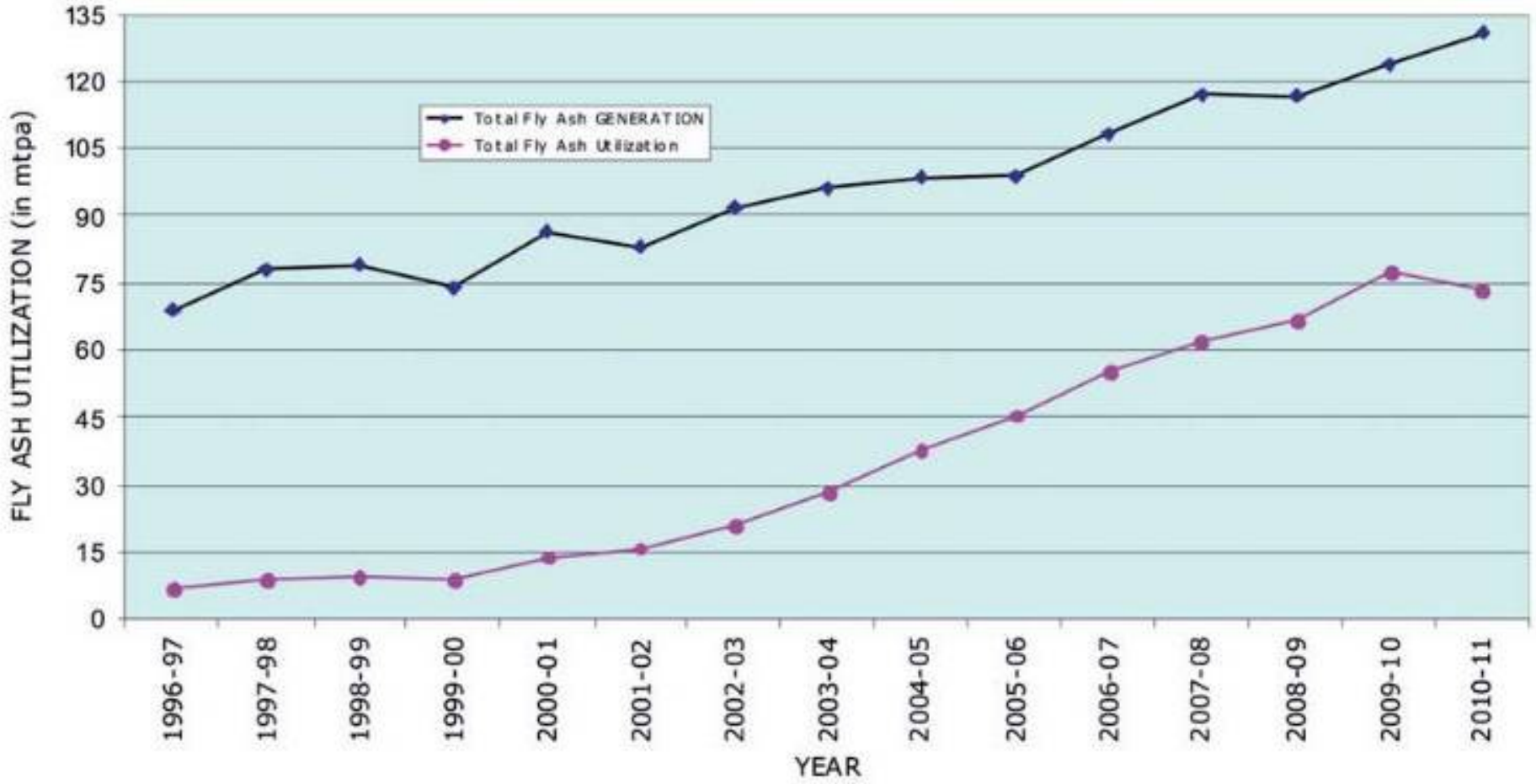
The gap remains and will even widen



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The Problem is global……also offering opportunities

	CHINA	INDIA	US
Cement Consumption	1,600 M ton/yr	265 M tons/yr	95 M tons/yr
Cement market price	US$45/ton	[redacted]	US$90/ton
Share of coal in power generation	80%	[redacted]	48%
Amount of ash produced	425 M tons/yr	[redacted]	85 M tons/yr
Current use of ash produced	30%	[redacted]	43%
Ash content in coal	25%-45%	[redacted]	6%-15%
Average ash disposal cost	n/a	[redacted]	US$ 15-20/ton
Ash production annual growth rate	15%	[redacted]	1%
Government mandated re-use of ash	n/a	100% by 2014	n/a

Source:

Indian Government reacts with the Fly Ash Directive

Company

(2) All coal and, or lignite based thermal power stations and, or expansion units in operation before the date of this notification are to achieve the target of fly ash utilization as per the Table II given below:

Serial Number	Percentag
(1)	
1.	At least 50%
2.	At least 60%
3.	At least 75%
4.	At least 90
5.	100% fly a

A job impossible!

Old Power Stations should have reached by now 100% fly ash recycling.
New Power Stations must reach 100% recycling in 4 years from start of operations..

Immediate relief could be to increase PPC production, change of the Standard for Fly Ash in concrete (permit more than 35% Fly Ash in concrete) and ban the production of clay bricks……How?

Create SECURE and economically BENEFICIAL building materials from Fly Ash

Increase the scope of cementitious applications of Fly Ash

Eradicate the misuse of Fly Ash

Make the Polluter pay

Continue the research in to new futuristic applications

More or less no use In India
Rihind Dam used 15 % FA as cement replacement in 1960

Limited use on projects and cement production

Extensive use in concrete and cement production

Indian Standard 3812 In 3 parts. Part 1: Fly Ash as Pozzolana
Part 2: Fly Ash as admixture
Part 3: Fly Ash as an aggregate

Dirk installs its first Fly As classification plant in Nashik and created the POZZOCRETE brand

Expected developments:
Subject: increased Admixture 35% ++

1966 → 1981 → 2000 → 2003 → 2013 → now

First Revision:
Single Standard 3812 (Part1)

Second revision of IS 3812 (part 1 and2)

Subject Uniformity

Third Revision
of IS 3812 (part1

Subject: Fly Ash in Cement)

B	C	D	E	F	G	H
Test	Unit	ASTM 618	EN 450		BS 3892	IS 3812
			Category S	Category N		
neness - Specific Surface by laine's Permeability Method	m2/kg	Not Specified				320
DS 25 micron sieve	%					
DS 45 micron sieve	%	34.0	12 max	40 max	12.0	34.0
oss on Ignition(Max.)	%	6.0	7.0		7.0	5.0
'ater Requirement	%	115%	95% max	Not Specified	95% max	
oisture Content(Max.)	%	3.00			0.50	2.00
oundness by Autoclave		0.8%	10mm		10mm	0.80%
ompressive Strength At 28 days - % f Plain Cement Mortar	N/mm2	75%	75%		80%	80%
me Reactivity(Minimum)	N/mm2					4.5
hemical Analysis						
$SiO_2 + Al_2O_3 + Fe_2O_3$	%	70.0 min	70.0 min		Not Specified	70.0 min
SiO_2	%	Not Specified	Not Specified			35.0 min
Reactive Silica	%		25% min			20.0 min
MgO	%	-	4.0 max			5.0 max
CaO	%	10.0 max	10.0 max		10.0 max	Not Specified
SO_3	%	4.0 max	3.0 max		2.0 max	3.0 max
Na_2O	%	Not Specified	5.0 max		Not Specified	1.5 max
Total Chlorides	%	Not Specified	0.10 max		0.10 max	0.05 max
Independent verification						

International and Indian Standards for Fly Ash in structural concrete

मानकः पथप्रदर्शकः

Fly Ash which does not meet ALL tests specified in IS 3812 Is not fit to be used in structural concrete

- The Fly Ash particle size varies from 1 µm to 150 µm.

- **Typically, the size less than 10 µm contribute to the pozzolanic activities. Size above 45 µm hardly contributes to pozzolanic activities.**

- The specific surface area as tested by Blaine technique and as collected by ESP is found to be about 400 to 700 m^2/kg as compared to specific surface area of cement 260m^2/kg (average).

- Specific gravity of fly ash varies widely but it is taken as 2.2.

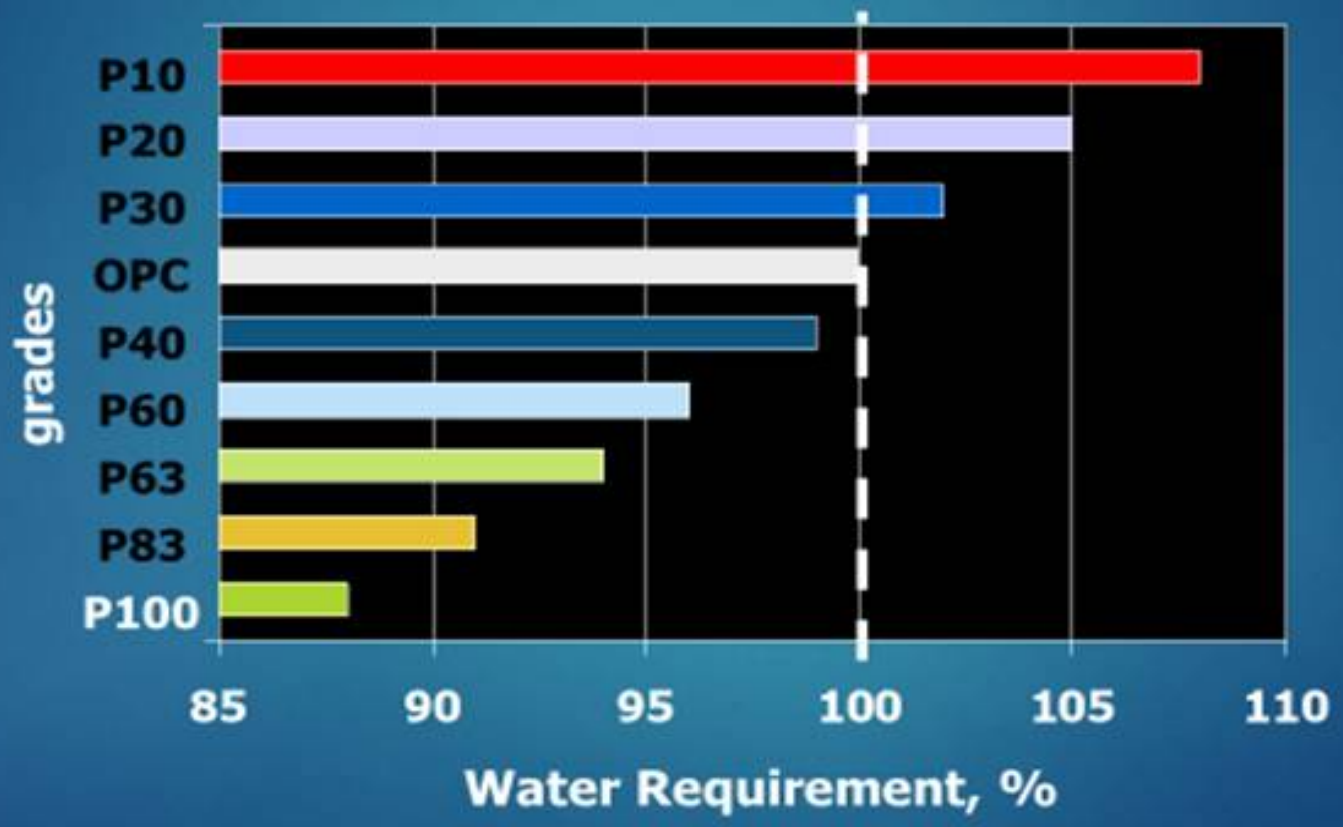
The most important Fly Ash criteria of the Standard are:

Particle size, water requirement and Carbon content. PHYSICALLY

Pozzolanic reactivity, CHEMICALLY

Strength , combination of Physical and Chemical properties

Classified Fly Ash: Water Requirement



Percentage of fly ash in cementitious material	Reduction in water content kg/m³				
	Slump (mm)	0 – 10	10 – 30	30 – 60	60 - 150
10		5	5	5	5
20		10	10	10	15
30		15	15	20	20
40		20	20	25	25
50		25	25	30	30

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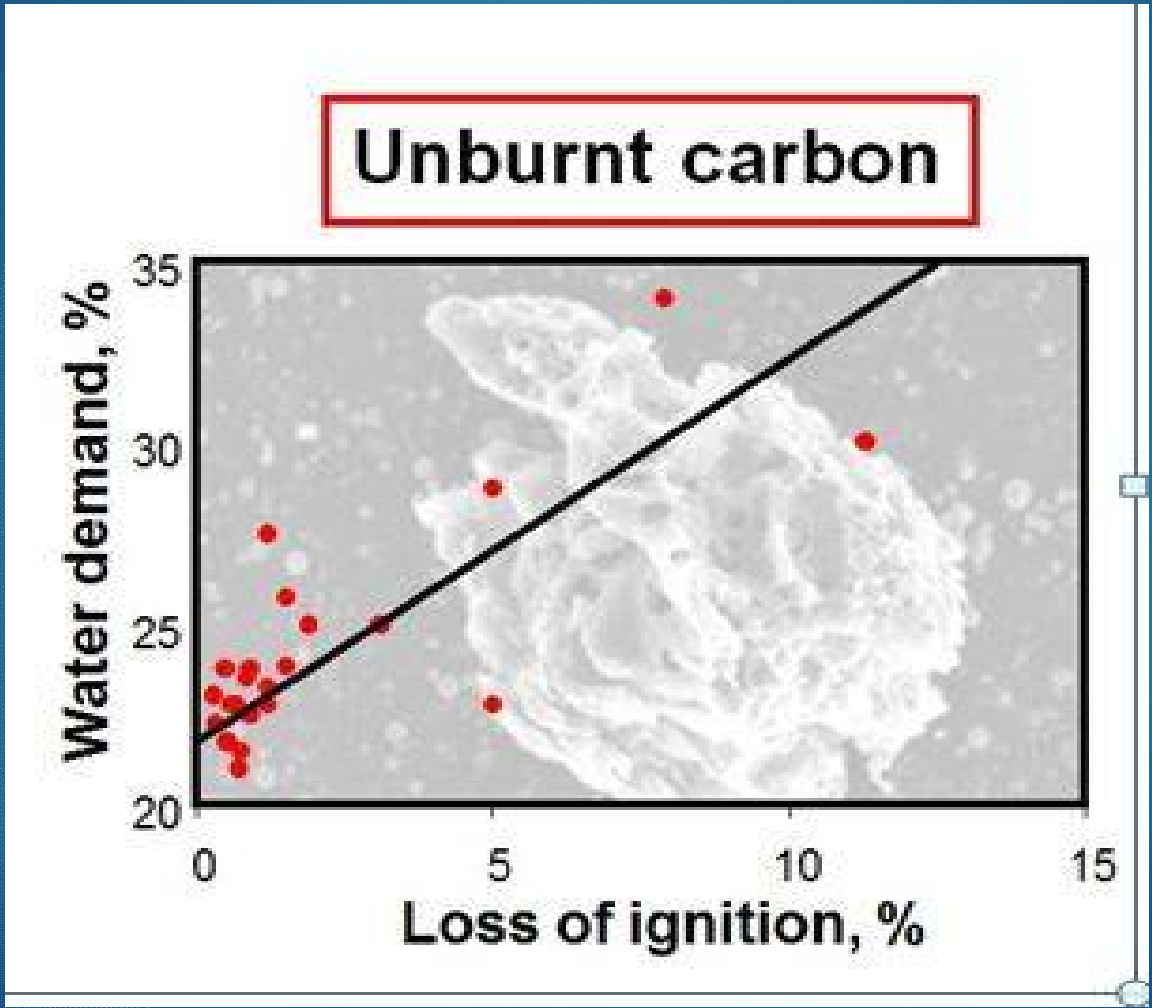
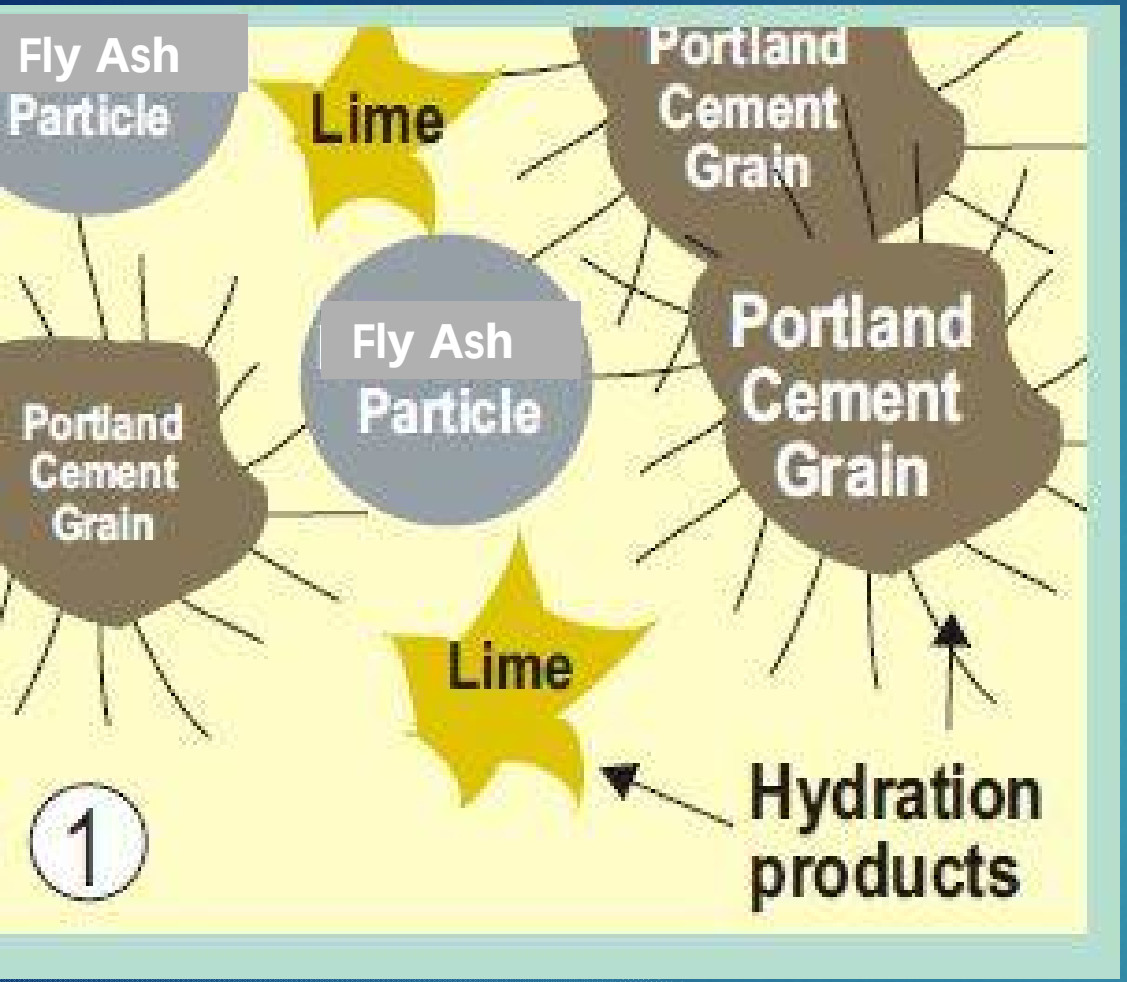
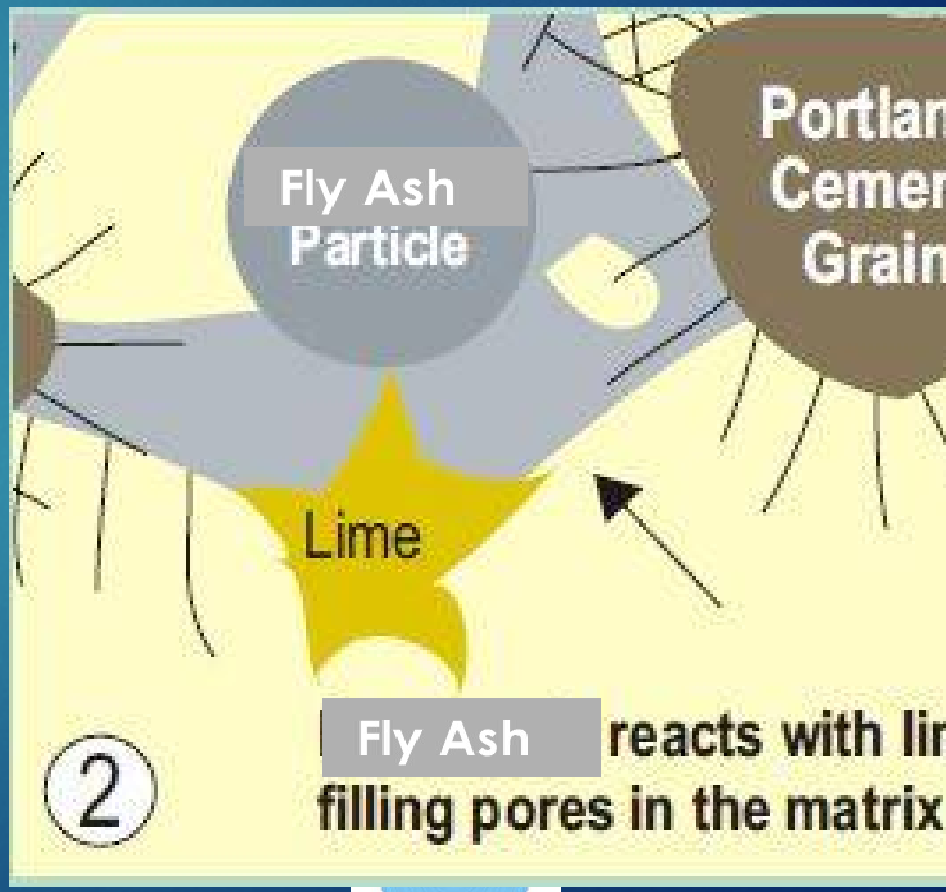


Pozzolanic Reaction of Fly Ash





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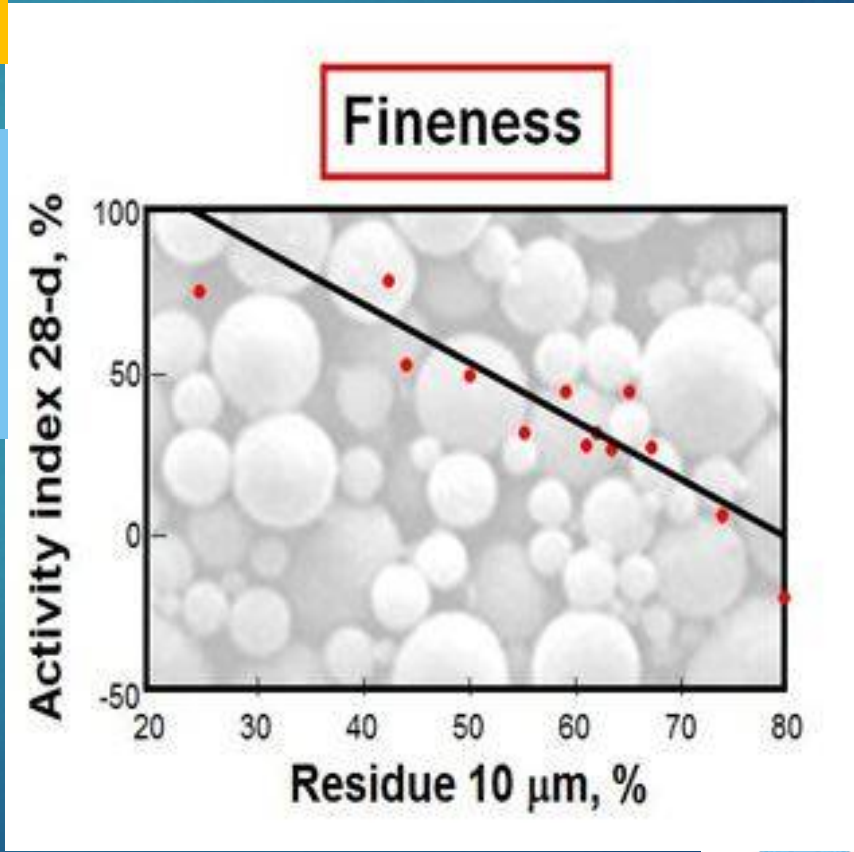
Raw Fly Ash particle size, as collected, is 0% - 100% retention on 45 my sieve

The main effect of fineness is the filling effect (packing)
And the reducing water requirement.

How to get to fineness?

Surface increase (fineness) has effect on the Pozzolan reaction



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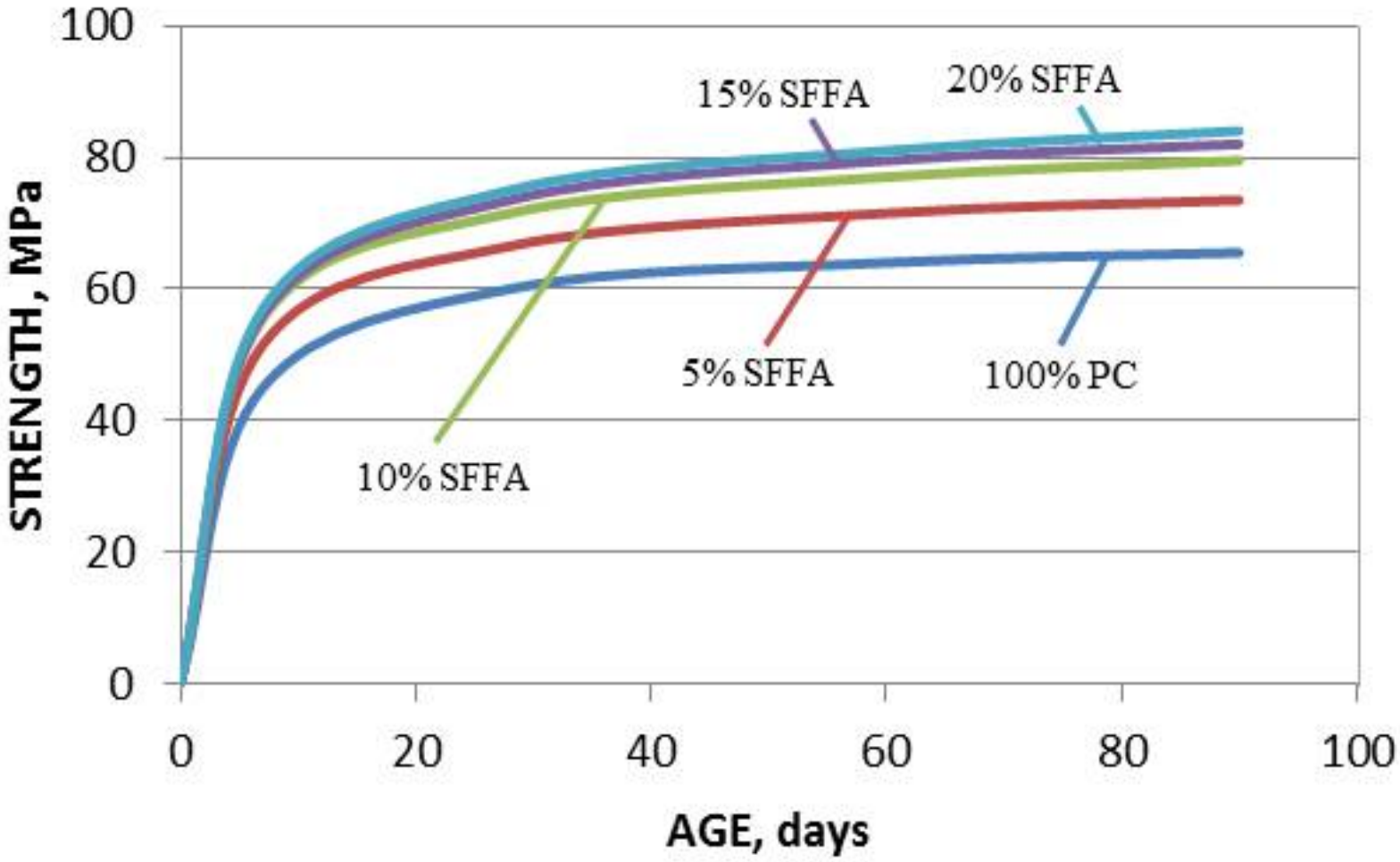

As a result of the limitations stipulated by the Standard we can expect the following when using Fly Ash in concrete

Reduced shrinkage
Reduced cracks
Improved workability
Reduced bleading and segregation
Reduced slump loss
Reducd heat of hydration
Improved finishing
Increased ease of pumping
Increased Chlorine as SO4 resistance

Perhaps the greatest disadvantage associated with the use of Portland Cement Concrete is cracking due to drying shrinkage.

Drying shrinkage is influenced by quality and amount of cement paste. In other words drying shrinkage is influenced by water content and cement content

Water reducing property of fly ash and reduction in paste volume is of great advantage in reducing the drying shrinkage.

Fundamentally the reduction of mixing water and reduction of paste, improves the resistance to corrosion, alkali – aggregate expansion, sulphate attack, chloride ion penetration, carbonation and in general the total durability of concrete.

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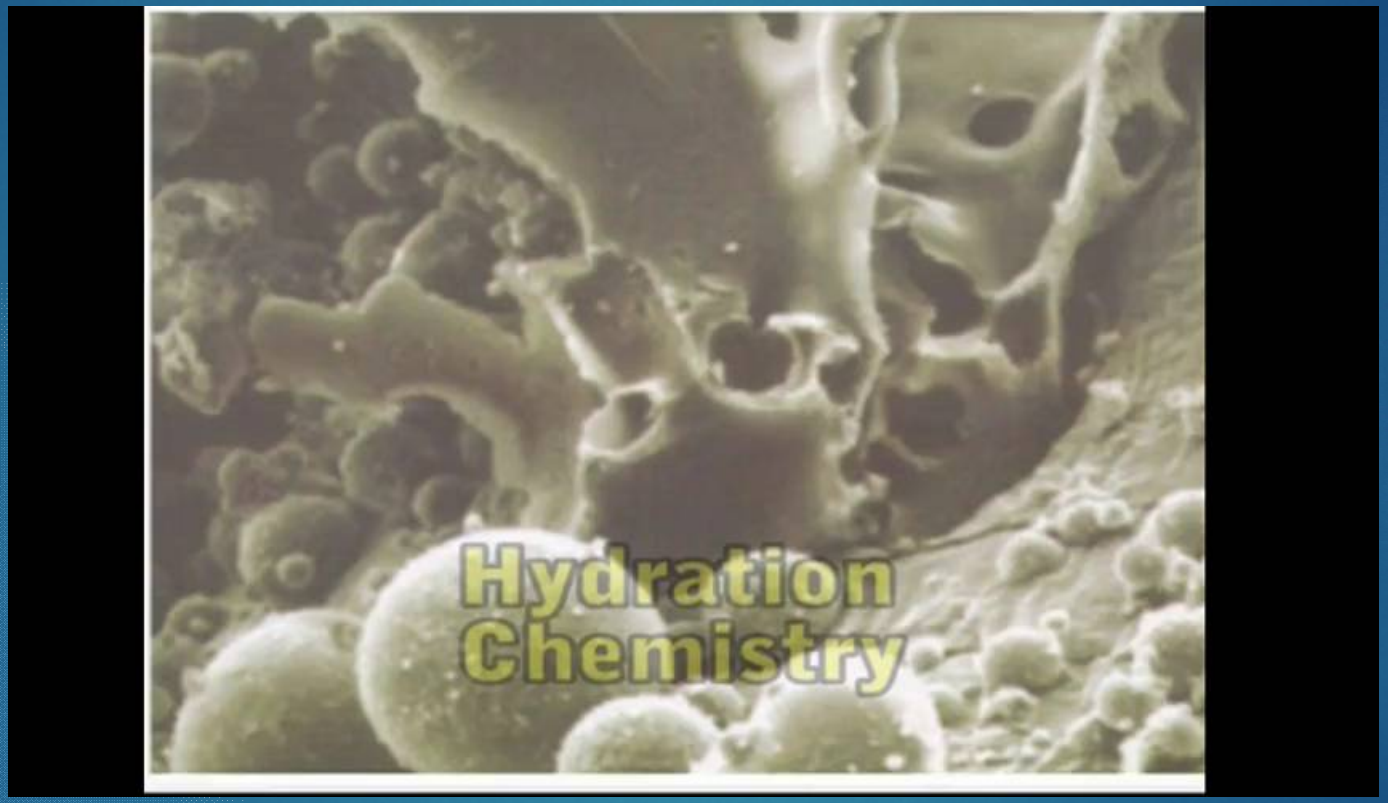
The Cement Hydration



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The Pozzolanic reaction

Due to use of pozzolana blended cement in concrete, additional
calcium silicate hydrate (C-S-H) gel is produced because of pozzolanic reaction, which is the reaction between pozzolan and Ca(OH)2 (lime) that is liberated from hydration reaction of
Portland cement. Due to more production of C-S-H gel, mechanical and durability
performance of concrete improves

What is meant by processing of Fly Ash?

Selection of a certain particle size and Particle Size Distribution out of the raw Fly Ash stream
(A physical process with chemical consequences)

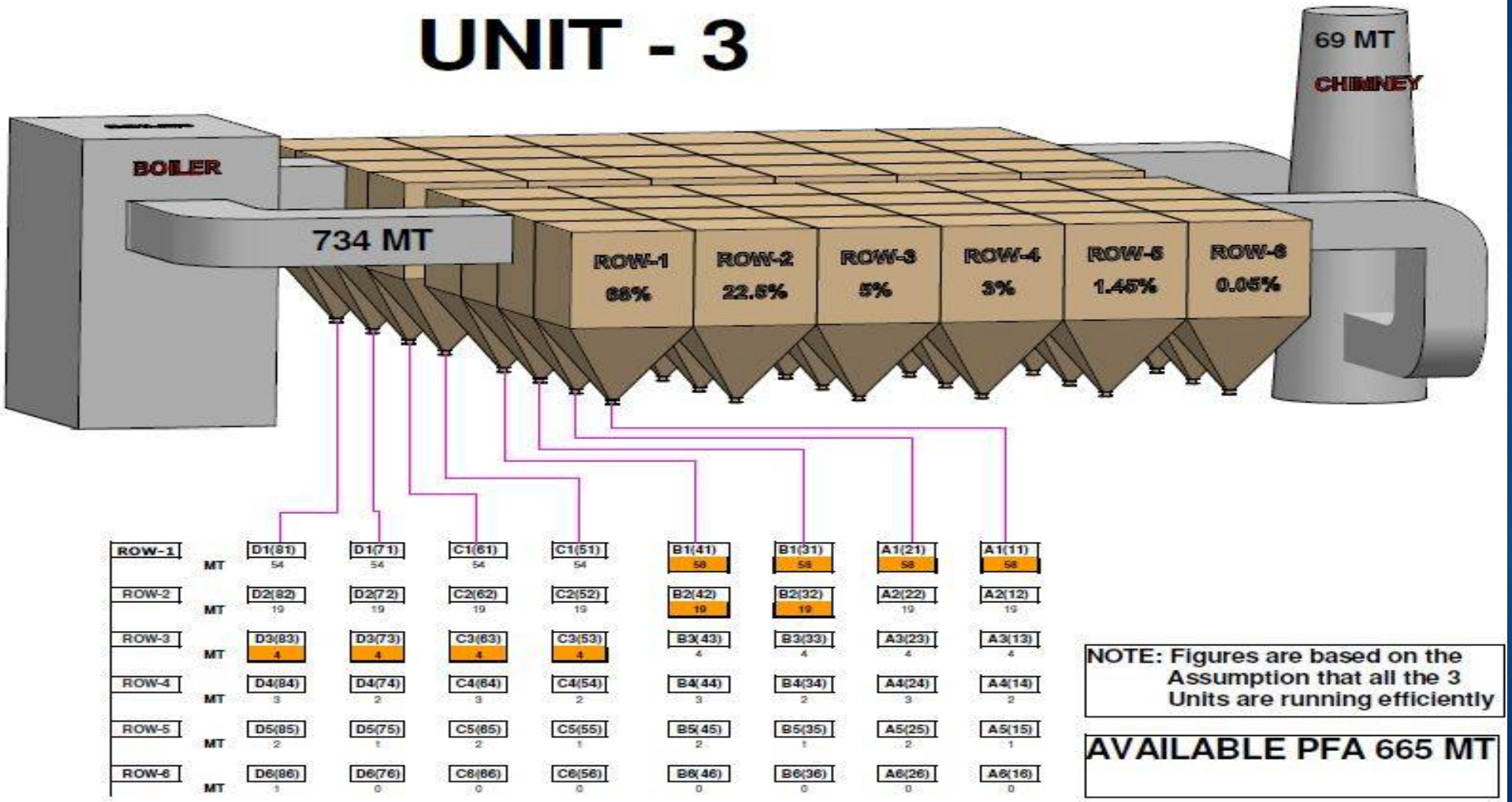
Elimination or reduction of unburnt carbon in the separated fraction (to avoid hampered hydration caused by water absorption of carbon particles) max. 5% is permitted in Indian Standards.

Ammonia removal from the raw Fly Ash Stream (to avoid gaseous emissions when mixed with water) max. 110 ml NH3 /L is considered acceptable.

Alcali/Sulphate Chemical, Mechanical and Physico-Chemical activation of the separated fraction (to increase the reactivity of Fly Ash if % of Alo2 and Sio2 and Fe2o3 are insufficient) Standards require combined 70%.

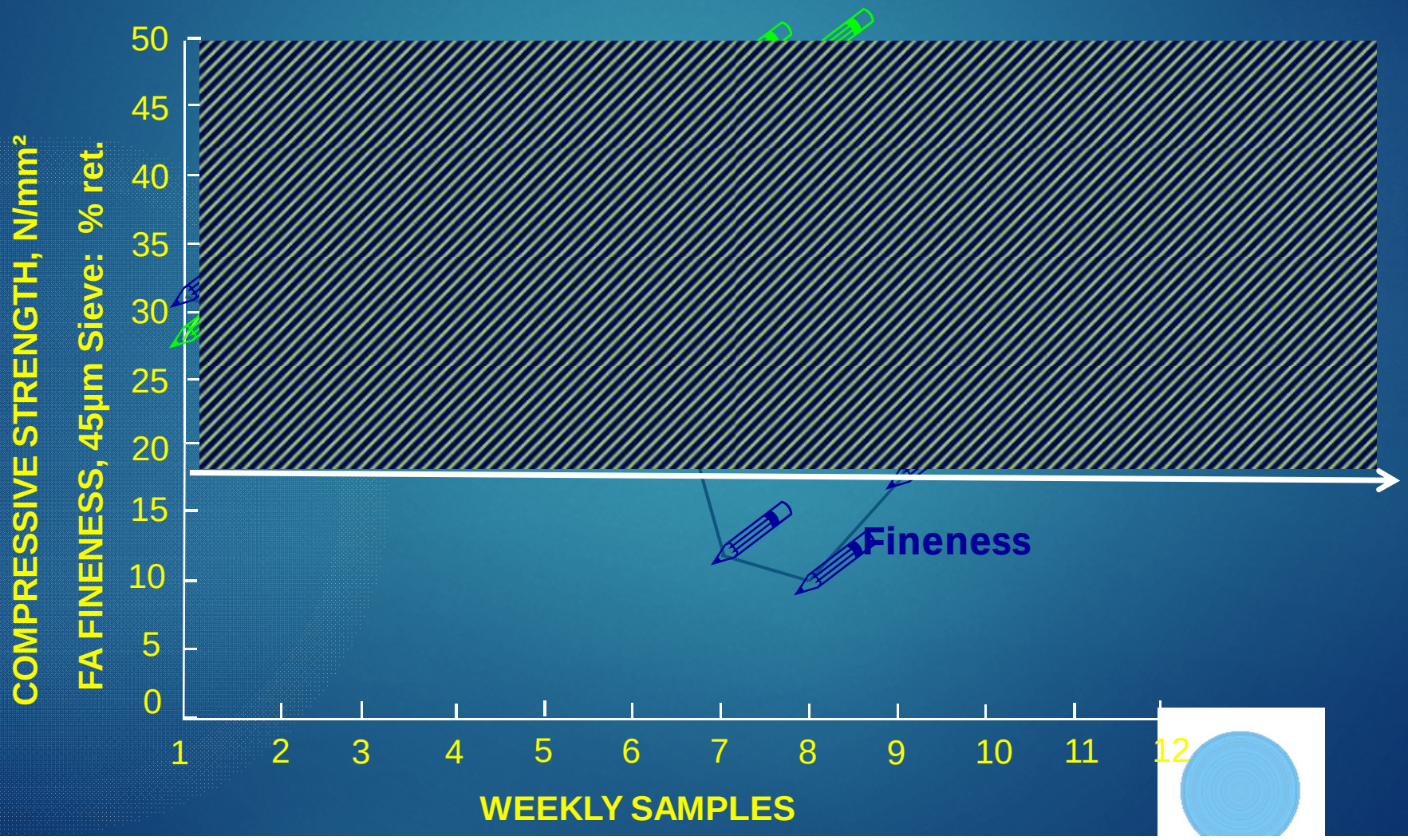
Actual ash availability by row / example Unit 3 NTPS

Is this classication good enough??



Dirk India Fly
Ash process
plant at Na

Fluctuations in Run of Station Fly Ash over time



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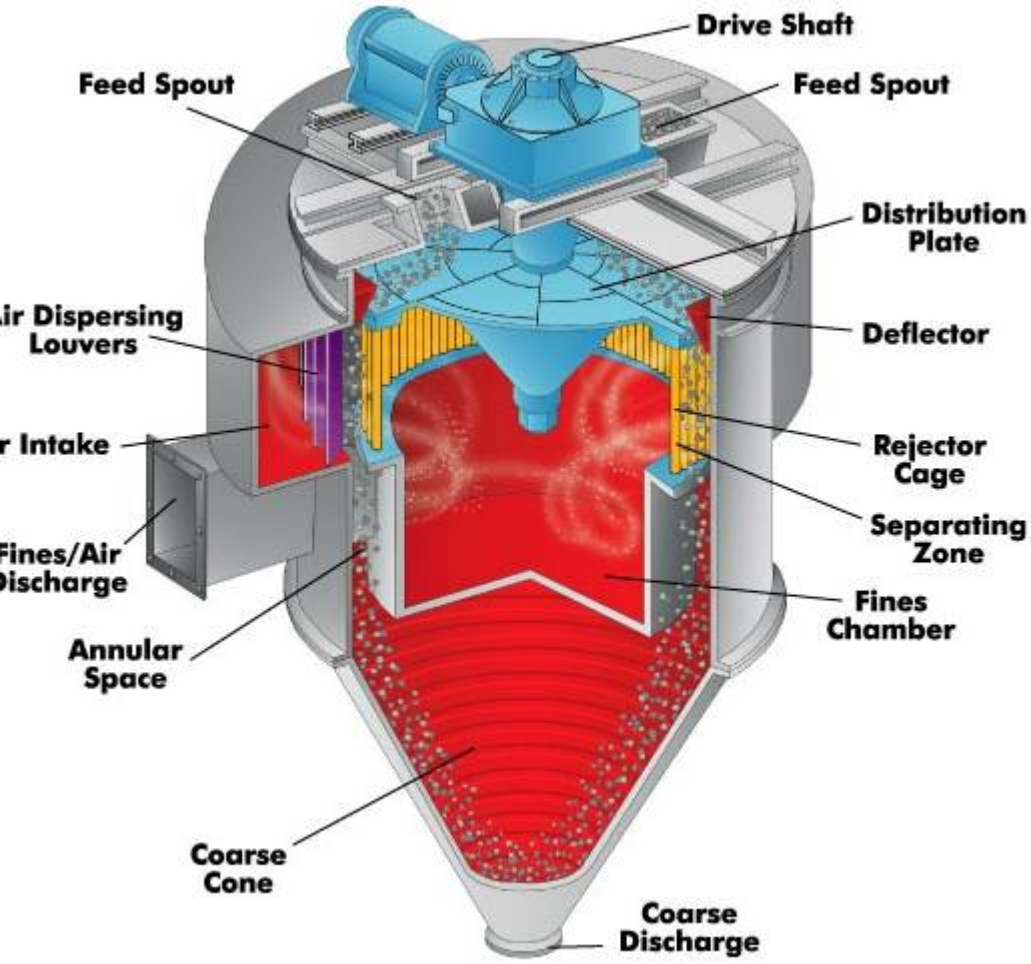
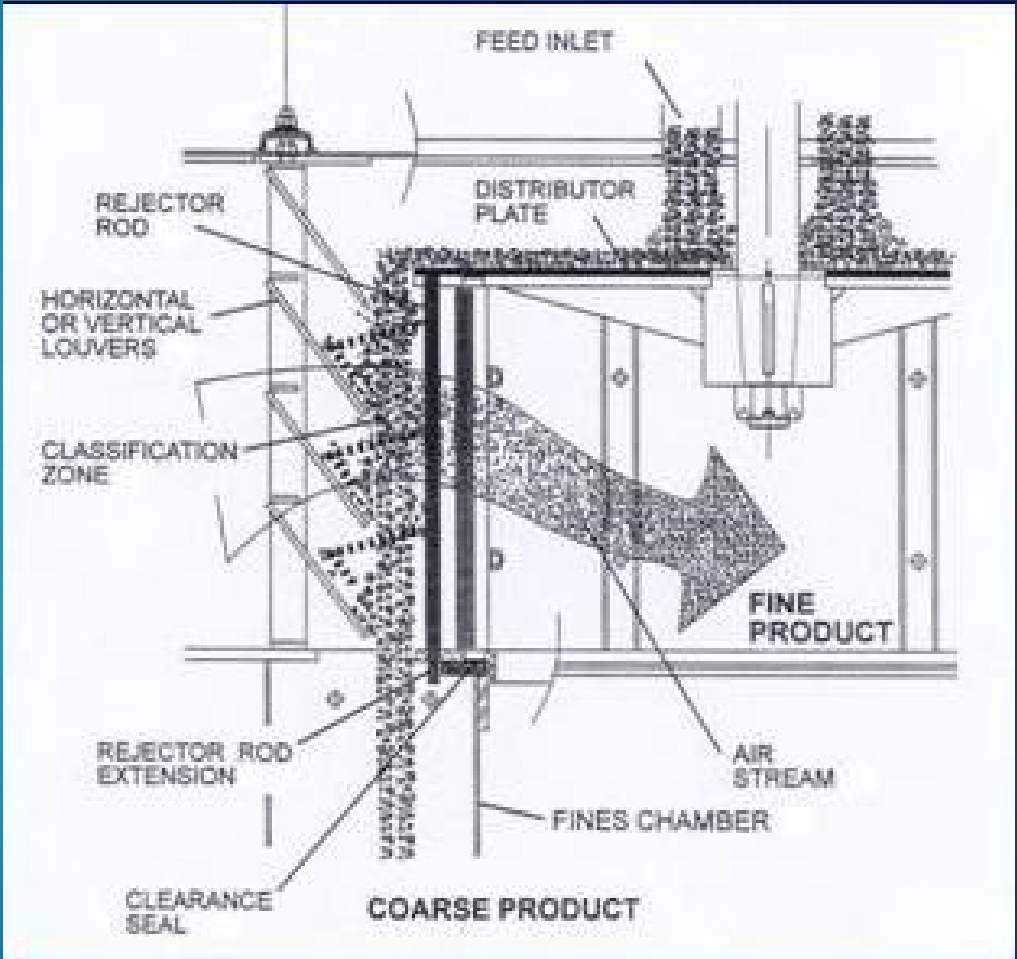
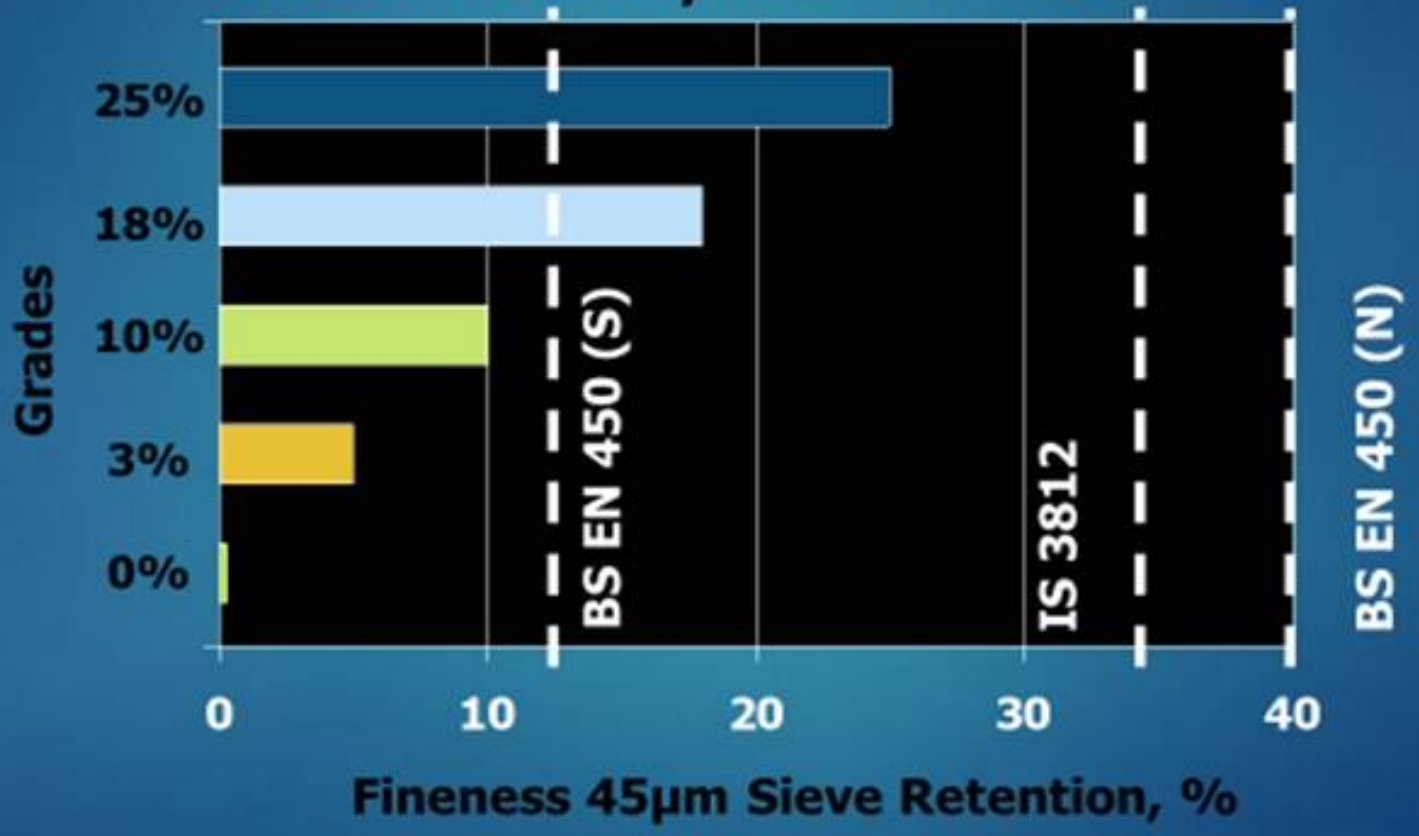
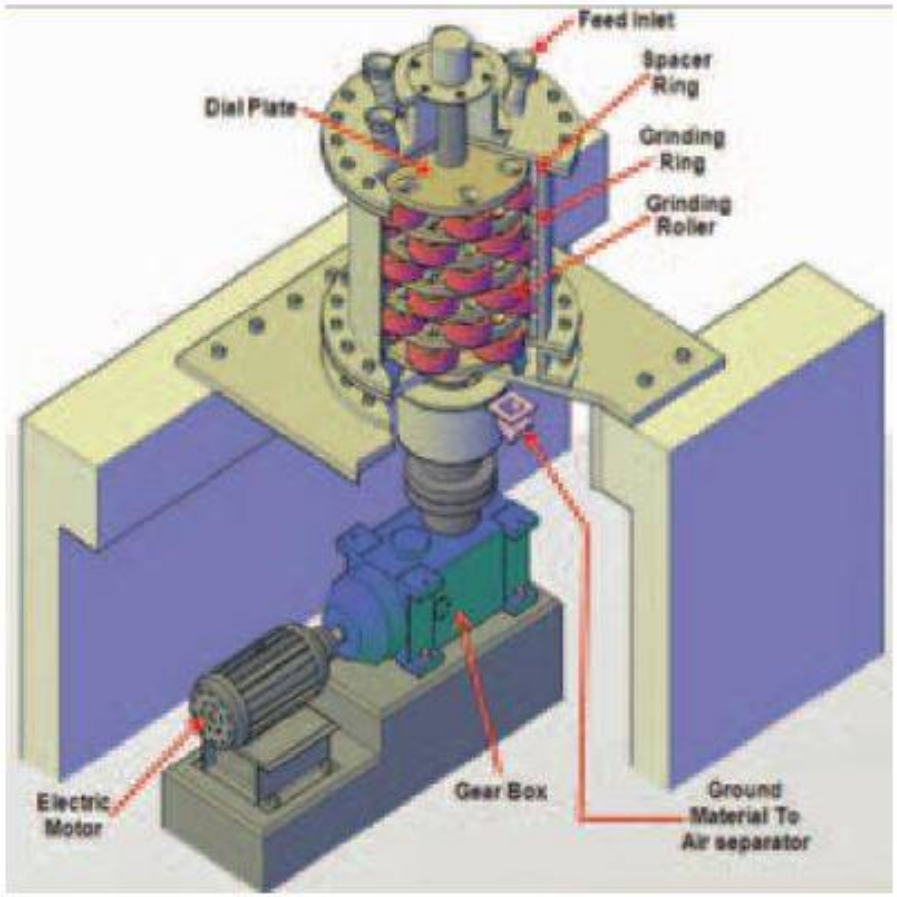




Classified Fly Ash: Fineness



The alternative to classification: grinding



Particle shape comparison: classified vs ground

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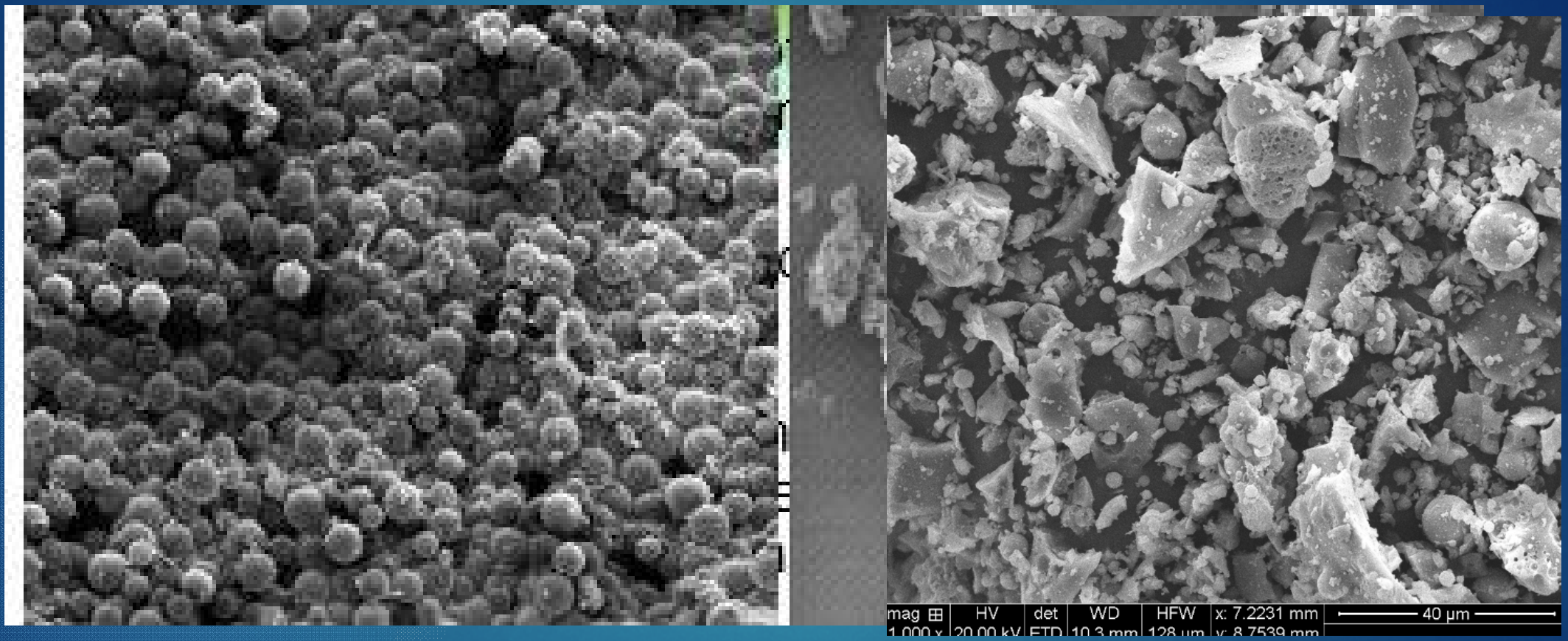

le 2 : Effect of fine fly ash (FFA) and microsilica fume (MSF) on durability of concrete

EMENT	DURABILITY PROPERTIES			
	ISAT10, $ml/m^2/s \times 10^2$	k_{int}, $m^2 \times 10^{-17}$	ASTM Chloride, Coulombs	8 Weeks Carbonation, mm
Table 2 Effect of fine fly ash (FFA) and microsilica fume (MSF) on durability of concrete				
rtland Cement at w/c = 0.40	35.5	3.6	Moderate	5.4
Addition, 5%				
A 5% at w/c = 0.368	29.5	1.6	Moderate	4.0
F 5% at w/c = 0.413	31.5	1.1	Low	9.4
Addition, 10%				
A 10% at w/c = 0.350	28.0	0.9	Low	3.5
F 10% at w/c = 0.425	31.0	0.9	Low	9.4
Addition, 15%				
A 15% at w/c = 0.345	30.0	1.0	Low	4.4
Addition, 20%				
A 20% at w/c = 0.338	32.0	1.2	Low	5.6

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Comparison of Ground and Classified Fly Ash (P60)

Concrete	Water l/m3	Strength, MPa			RCPT Coloumb	Water Permeability mm
		3 Day	7 Day	28 Day	28 Day	28 Day
OPC	170	37.0	51.0	62.0	3435	30.0
P60-CL	155	26.5	39.0	56		
P60-G	170	21.5	31.0	49.0	3997	25.0

a. Reduced water demand in Classified P60 (155 liters) compared to 170 liters for P60G mix
b. Higher strengths for P60-classified than P60G
c. Better RCPT & Water permeability for P60-classified than P60G

Issue of Pozzolanic Materials and Carbonisation of Concrete

Given that the pozzolanic reaction in a well cured concrete develops a denser pore structure, this through reducing the permeation of concrete will make up for the reduced alkalinity through the consumption of Ca(OH)2 in the pozzolanic reaction and the net effect should be marginal.

Whilst a perfectly logical, sound and simple explanation which appeared to work, the issue always remained and never went away.

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Design Strength: 40 MPa, FA content 25% W/C ratio 0.4, Slump 75 mm (European test results)

Fineness in % retention on 45 my sieve	Max strength at 28 days in MPa	Min strength at 28 days in MPa
5	47.5	44.0
10	44.0	39.5
20	38.5	32.5
30	35.5	38.0
40	33.0	26.5
50	28.0	21.5

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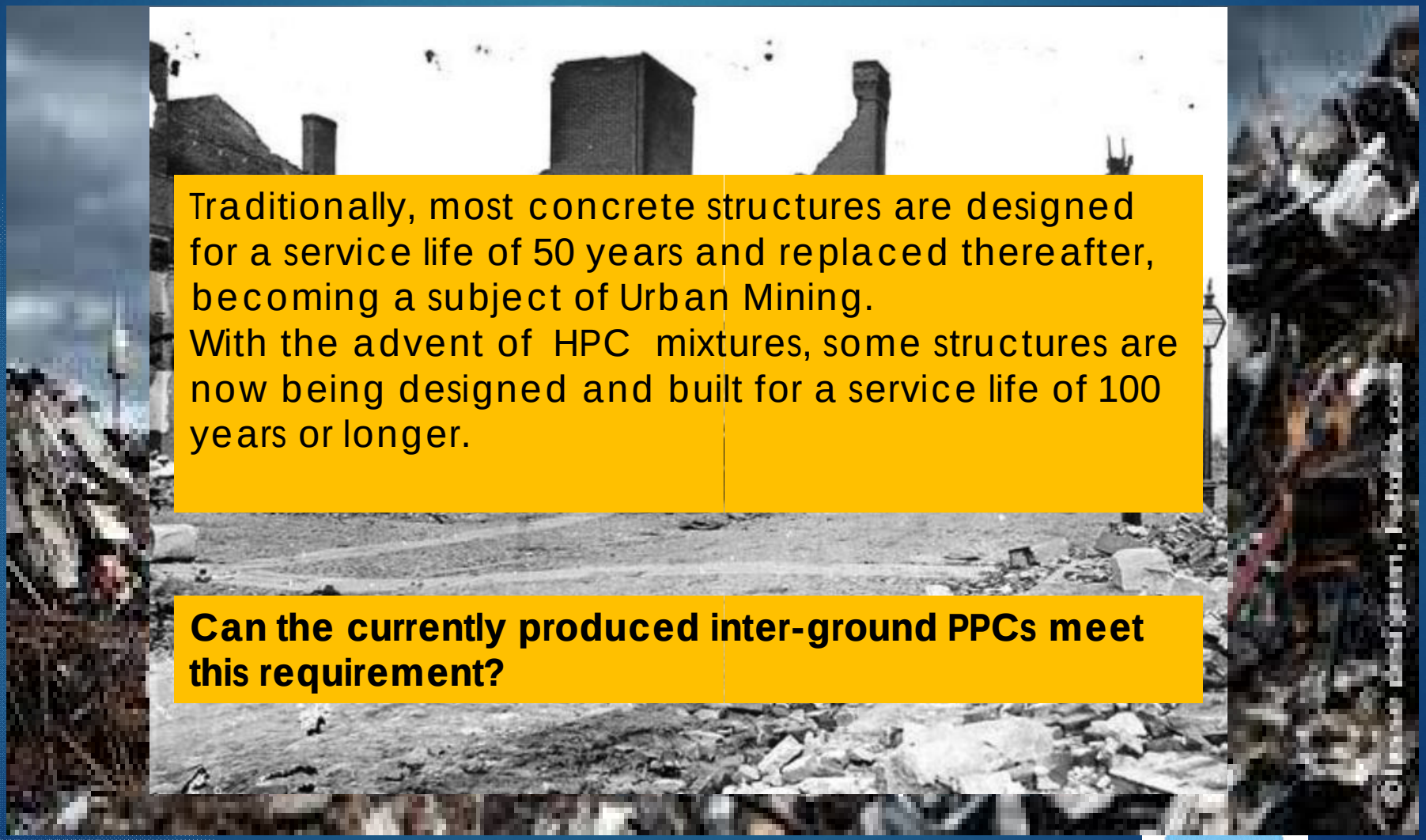

Traditionally, most concrete structures are designed for a service life of 50 years and replaced thereafter, becoming a subject of Urban Mining.
With the advent of HPC mixtures, some structures are now being designed and built for a service life of 100 years or longer.

Can the currently produced inter-ground PPCs meet this requirement?

The new official definition of HPC.

HPC is defined as a concrete meeting special combination of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices

Mehta and Aitcin suggested the term HPC for concrete mixtures that possess the following three properties:
high-workability,
high-strength,
high durability.

Why does inter-ground PPC not suffice?

us

The key to producing HPPC (High Performance Concrete) is to have a low w/c ratio.

HPPC means high strength (minimum 41 Mpa /some user groups set this strength limit to 50 or even 70 Mpa) with high durability and workability. The loss of spherical shape of fly ash in PPC does not allow the desired water reduction.

The use of super plastizisers does reduce the water demand, but one cannot use very high dosages of it in the mix, leading to delayed setting times.

The PPC manufacturers use the fly ash from the nearest available power stations. There is a strong possibility that the fly ash has high un-burnt carbon. On grinding of fly ash, the surface area of the un-burnt carbon is again enhanced. This again leads to higher water demand in concrete.

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Requirements of HPC (As per ACI)	Ground PPC	HPPC – Blended PPC
> 41 MPa *)	Confirms	Confirms
Durability (Higher than OPC)	Does not always confirm	Always confirms
Workability (better than OPC)	Does not confirm	Always confirms

The case is made:
We need an inter-blended HPPC for High Performance Concrete

High Durability to provide long service life of Concrete structures

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CEMENT TYPE	STRENGTH, MPa					WP mm	RCPT† coulombs
	1d	3d	7d	28d	90d		
High Performance Portland Cement Cement	31.5	44.5	50.5	95.5	to come	to come	1365
Fly Ash Blended Cement With:							
Microsilica Fume	28.5	32.5	38.5	96.5	"	"	1150
Ultrafine GGBS	34.5	41.0	54.0	85.0	"	"	1852
Metakaolin	29.5	37.5	53.0	91.5	"	"	1323
Ultrafine Fly ash	21.0	38.0	46.5	93.0	"	"	1149

The theoretical solution in two steps

Fly Ash activation
the way to largely increased Fly Ash utilization in India and increase of Fly Ash percentage in concrete.

1st Step

In 2012 240 million tons of cement were produced in India. 65% of this cement was interground PPC = 156 million tons

156 million tons contained on average 25% Flyash = 39 million tons of Fly Ash.

The aim is to produce all PPC to contain 35% Fly Ash = 55 million tons of Fly Ash (difference 16 milion tons).

This can be achieved by activating flyash either chemically or physically. Physically means by the extraction of ultrafine flyash from the raw flyash stream.

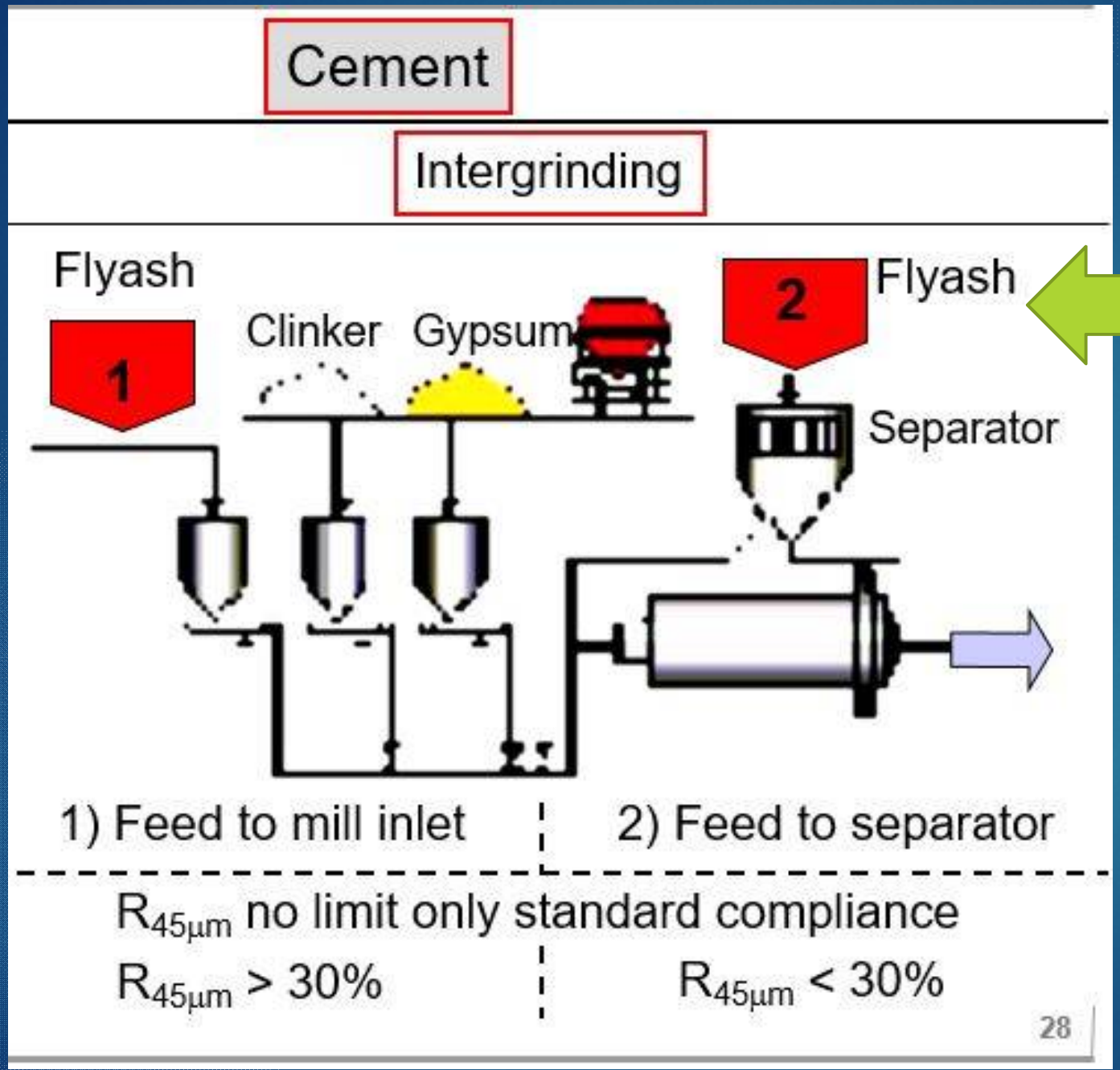
Dependant on BIS (change of Standard)

Dependant on production change to interblending

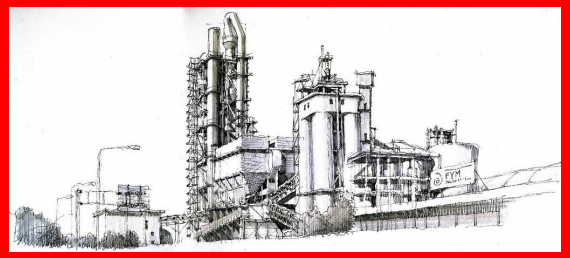
Second Step to increase Fly Ash Utilization in India

Both steps have the potential to save approx. 48 million additional tons of Fly Ash from being disposed of by being put to beneficial use in CONCRETE....but a new production and marketing model needs to be adopted .

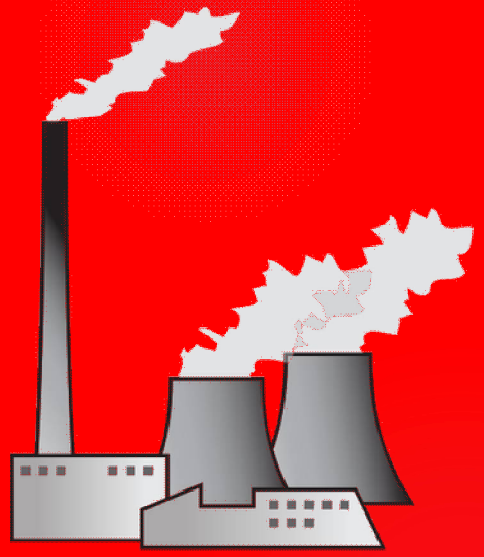
Dependant on market demand



Attempt to partially reduce the negative impact of Fly Ash inter-grinding



"retention" means , retention of 45 micron screen



Cement plant classifies "run off station ash in to:

1) 10% retention → 10% retention to be **interblended** with 53 Grade OPC (35% PFA) — **PPC+**

2) 0% retention → 0% retention + 10% retention +OPC **interblended (35%PFA** — **HPPC**

3) 75-100% retention → 75%-100% retention to be **interground** with OPC (30% PFA) — **PPC**

Power Station provides "run off station" PFA to cement plant

Portland cement clinker production is a dirty business (7% of all CO_2 emissions worldwide are related to this industry)

Power generation using coal as a fuel is also a dirty business (5% of all CO_2 emissions in India are related to coal fired power stations

On the other hand…….

For more information please contact us

Carbon footprint of Fly Ash versus other cement ingredients

Embodied CO_2 of cement, additions and other cementitious materials

Cement, Cementitious material	Embodied CO_2 (kg/CO_2 /ton
OPC	930
GGBS	52
Fly Ash from coal	4
Limestone 32	32
Minor add. Constituents	32

By producing a High Performance Pozzolan Cement the amount of concrete used in construction can be reduced by up to 35 % …… a massive positive impact on the environment and society.

Already today the Ready Mix Industry is able to produce such HPPC as they can make a triple blend with ultrafine PFA in their existing plants.

But still:

In India most PPC is still bagged in 50 kg bags and the consumer needs to have this triple blend in the bag he bought

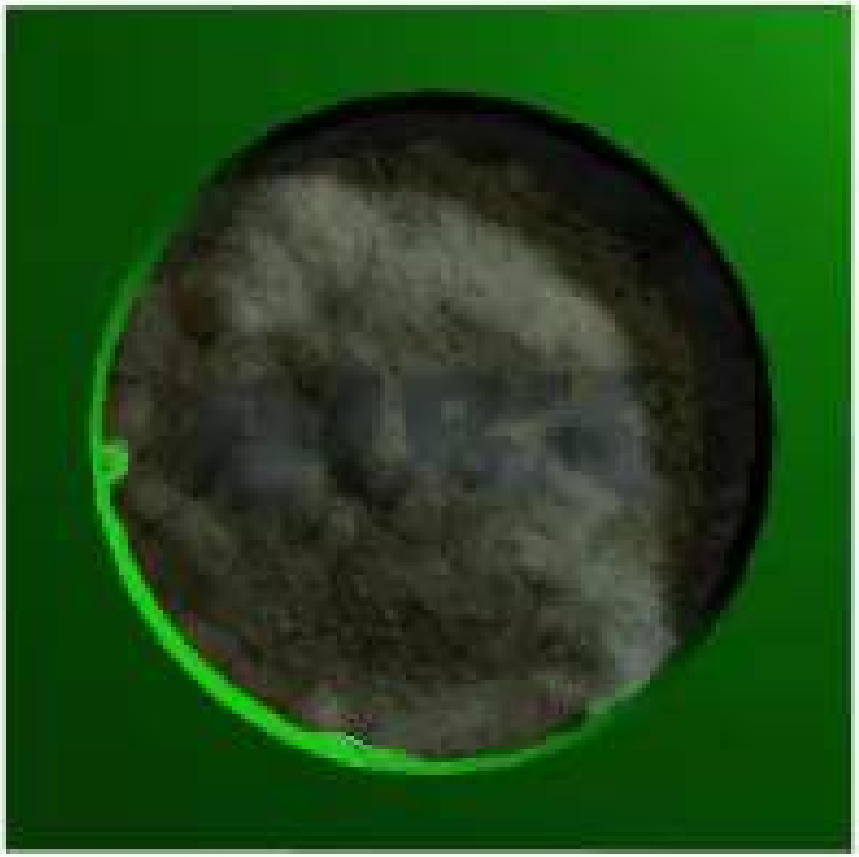
With my investment in to a Fly Ash processing plant at Nashik one of the main barriers for using PFA as partial OPC replacement was removed: fluctuating, unreliable particle size

By getting the Bureau of Indian Standards to grant its Standard Mark for the processed Fly Ash even more confidence was created

Because of this mass use of classified Fly Ash was sparked of as the cost price for a cbm concrete dropped by 20%

Finally in the year 2015 52 million mT of OPC will be replaced by Fly Ash saving around 48 million MT of CO_2 emissions only in this year.

I handed over my Nashik project with the hope that my successors will work to reduce Portland Clinker content, create a concrete with 100 years service life and by using High Performance Pozzolan Cement allow a reduction of 35% of concrete in structures.



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...available for advice....