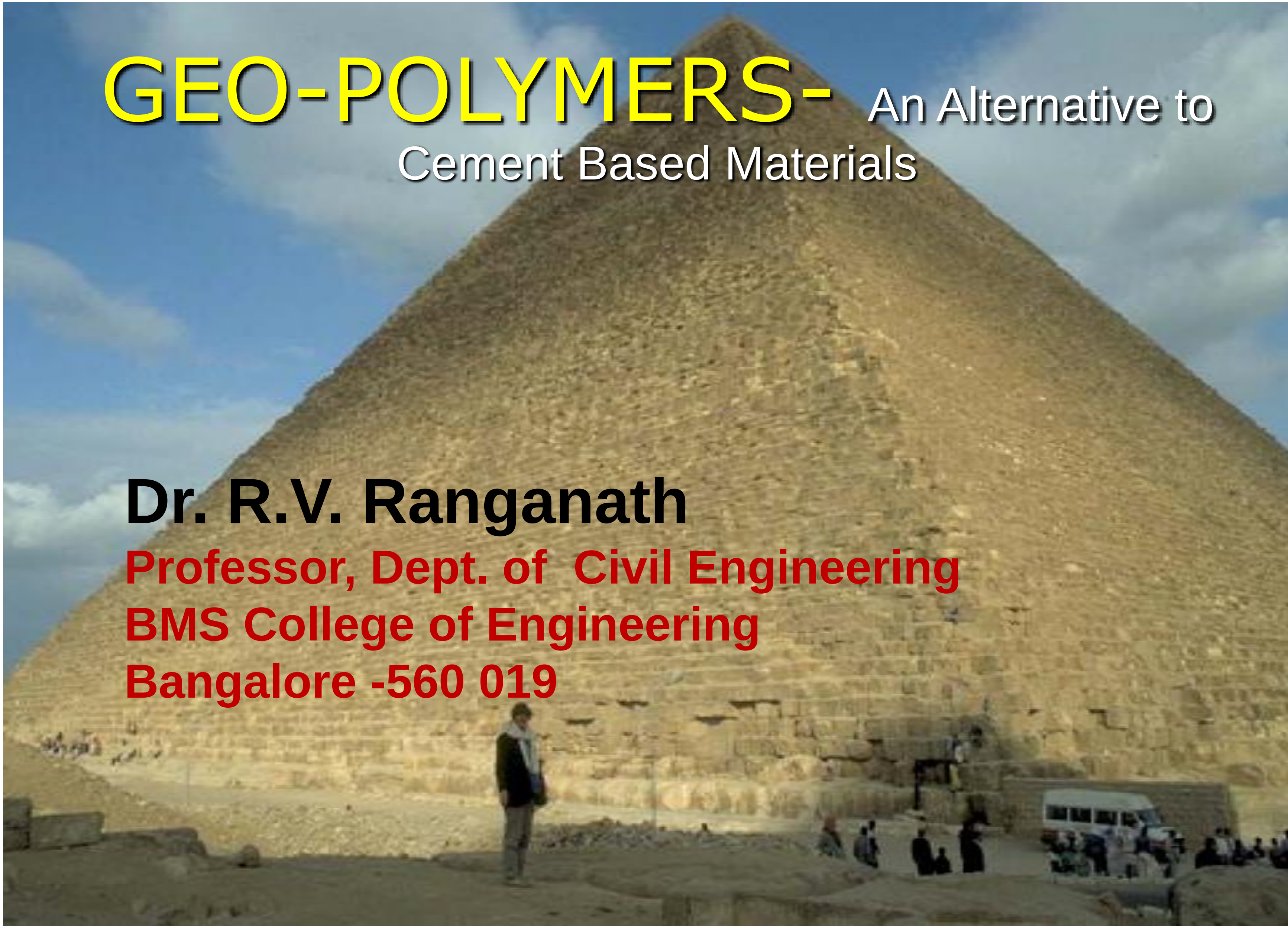
GEO-POLYMERS- An Alternative to Cement Based Materials



Dr. R.V. Ranganath
Professor, Dept. of Civil Engineering
BMS College of Engineering
Bangalore -560 019

Introduction

- *Developments in the field of Concrete Technology have been phenomenal in the last decade*
- *Several radical changes have also occurred in this field*
- *Self compacting Concrete, Self curing Concrete, Regulated sleeping Concrete, High volume Fly ash Concrete etc.., have all revolutionized the concrete Industry*
- *The latest in the series is the development of Geopolymer Concrete*

Portland Cement and Geopolymer

- **Portland Cement → synthesis of high CaO minerals, main product is C-S-H gel from the hydration process; <u>water is needed for the hydration process.</u>**

- **Geopolymer → results of polymerisation process of minerals containing Si-Al; <u>water is released during the chemical process.</u>**

GEOPOLYMERS

- ***Geopolymers are alkali activated Alumino silicate binders formed by reaction of silica and alumina rich materials with alkaline solutions.***

- ***The reaction results in a mixture of gels and crystalline compounds which harden into a strong matrix.***

- ***A relatively low elevated temperature environment of about 60-80 Deg C is sufficient for geopolymerisation, unlike organic polymers which often require higher levels of temperature.***

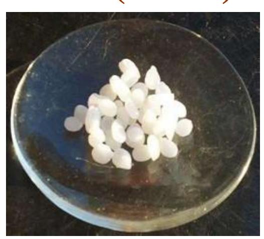
Flyash

OR

GGBFS

+

Alkali (NaOH)



+

Sodium Silicate

=

Geopolymer paste

polymeric material Si–O–Al–O bonds

-an inorganic alumino–silicate polymer

Metakaolin, Rice husk ash,

MECHANISM OF GEOPOLYMERISATION

- ***One of the 'visualised mechanism' of Geopolymerisation' is***

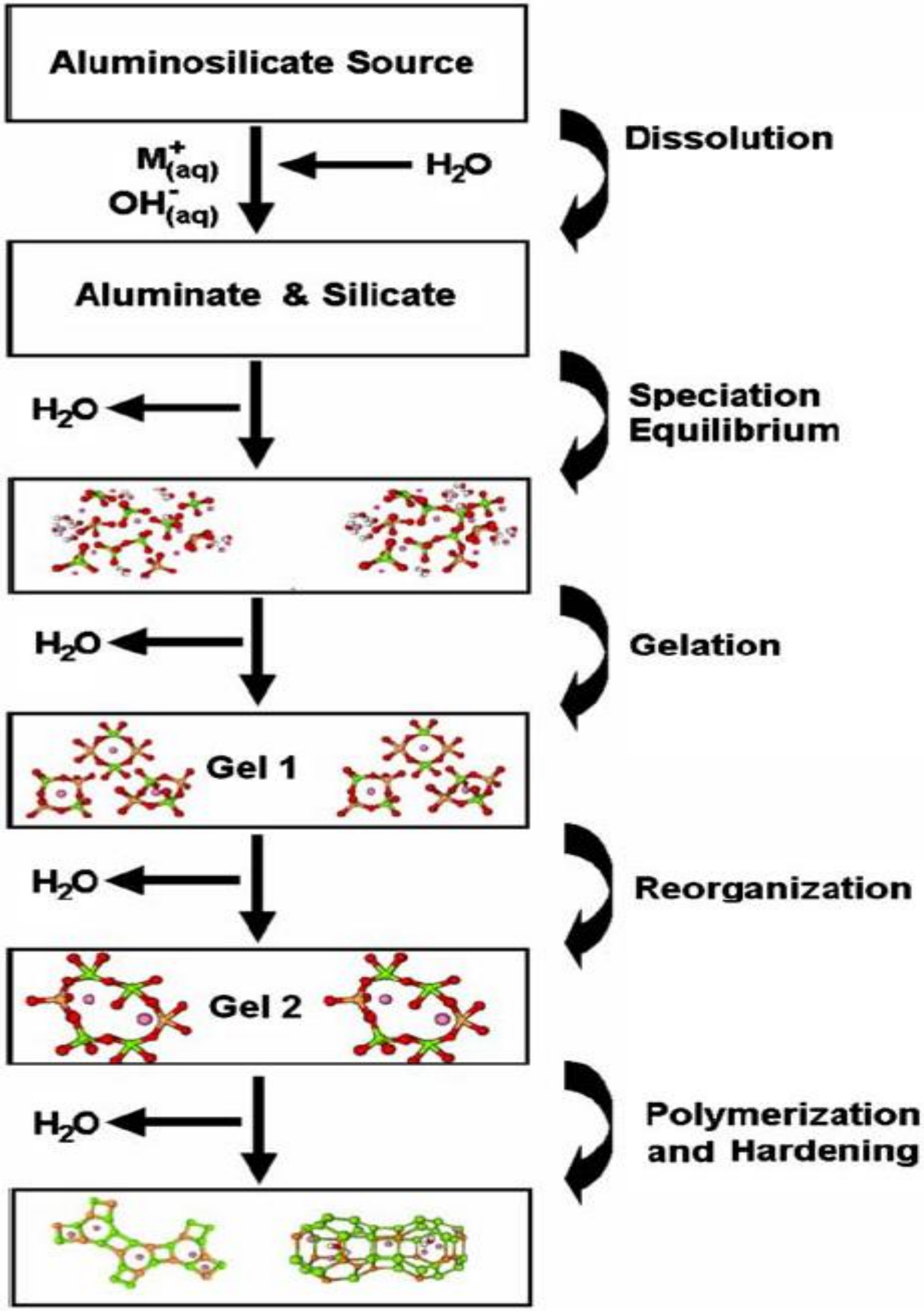
Dissolution

Gelation

Reorganisation

Polycondensation

Reaction takes place through an exothermic process



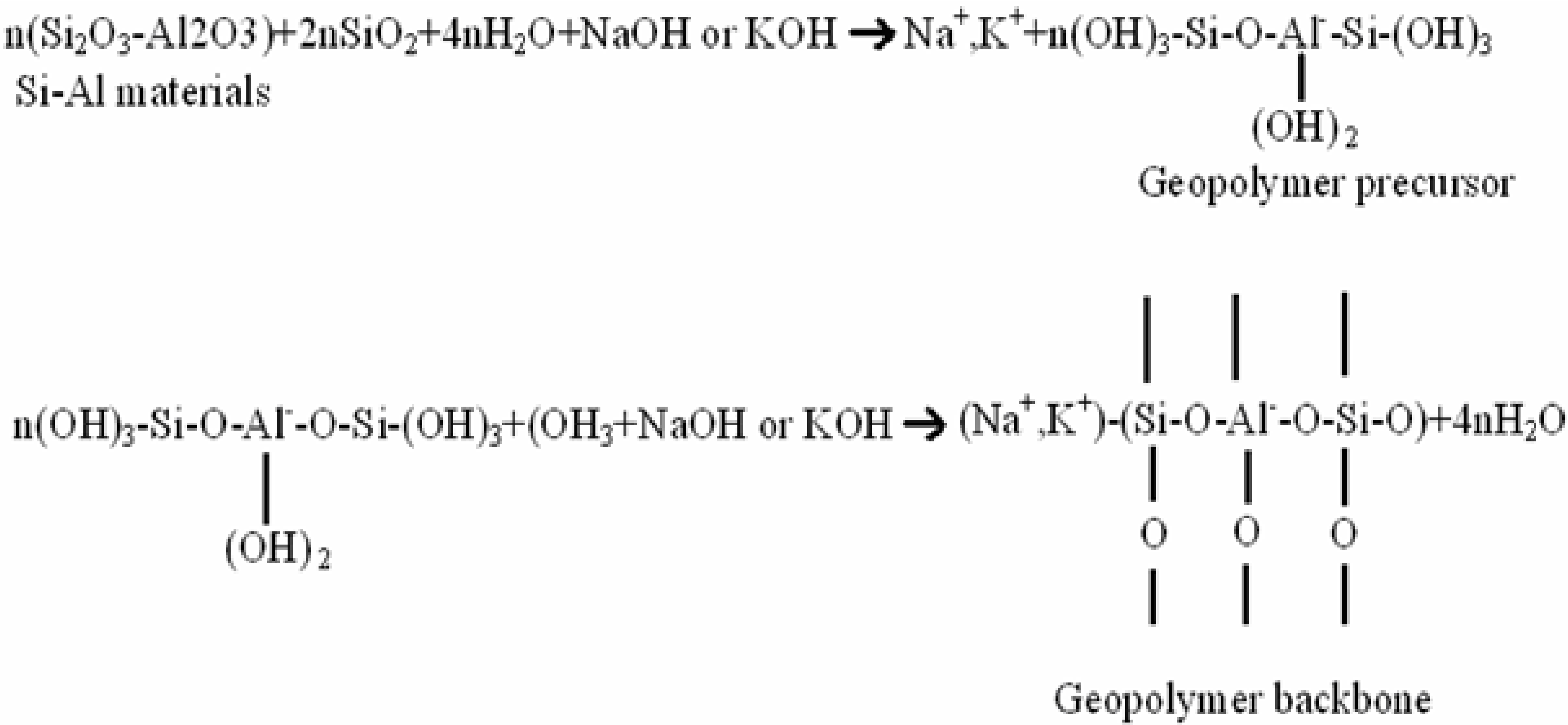
CONCEPTUAL MODEL

- *The polymerization process involves a chemical reaction under highly alkaline conditions on Al-Si minerals, yielding polymeric Si-O-Al-O bonds, as described by*

$$\mathbf{M_n [\ - (Si - O_2)_z - Al - O]_n\ .wH_2O}$$

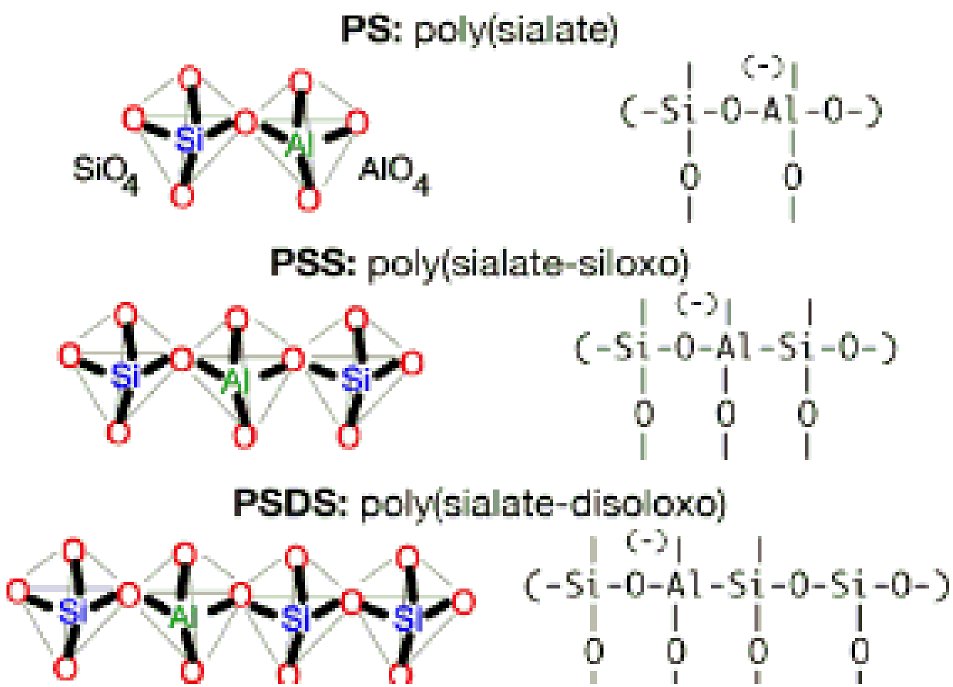
- *Where M is the alkaline element, the symbol – indicates the presence of a bond, z is 1,2 or 3 & n is the degree of polymerization.*

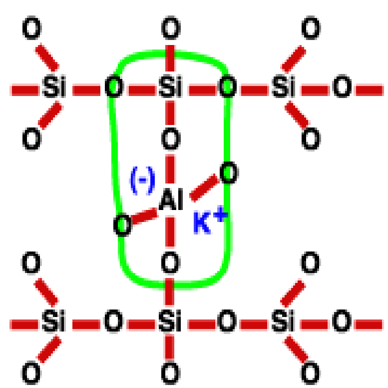
Schematic Formation of Geopolymer

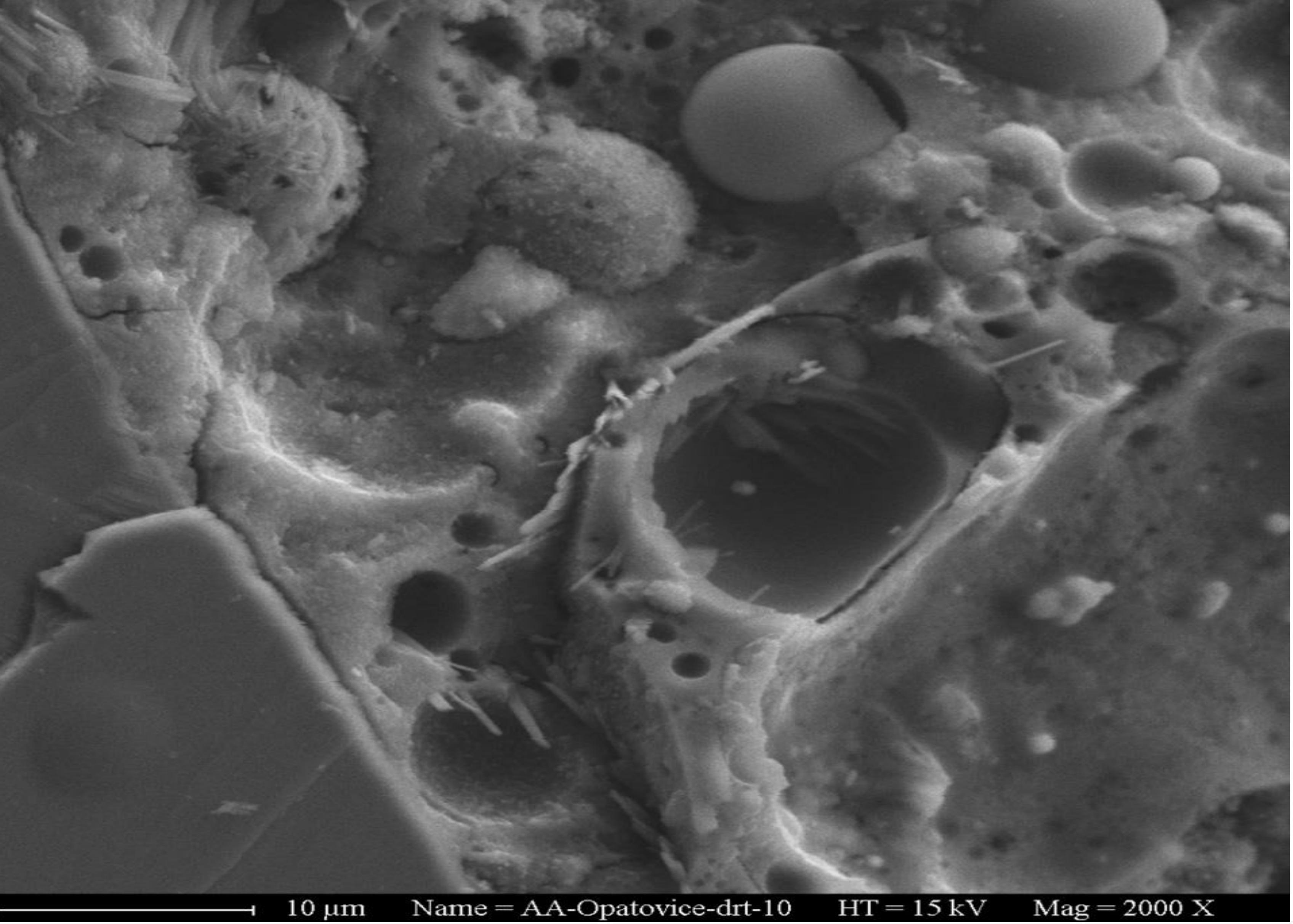


The rate of polymer formation is influenced by parameters such as curing temperature, alkali concentration, initial solids contents, etc.

CHEMICAL STRUCTURE





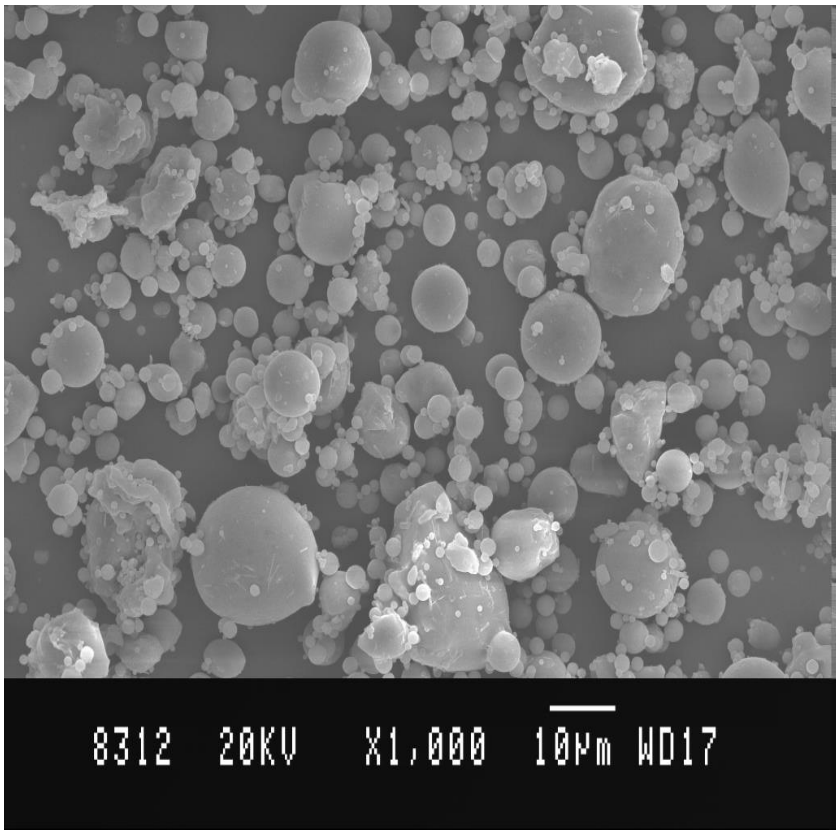


GEOPOLYMER- SEM

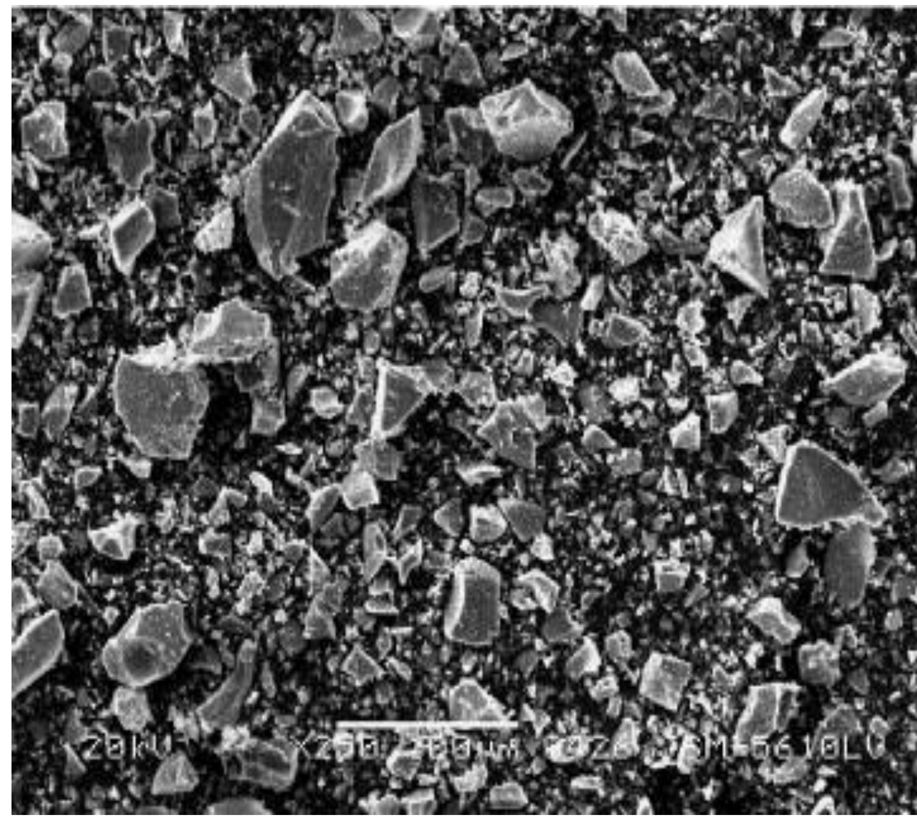
GPC with Fly ash/Slag – Some studies..

Materials

Fly ash



GGBS



Physical properties of Fly ash and Slag

Parameters Tested	UFFA	NFA	UFS	GGBFS
Glass content (% by mass)	36.60	19.20	94	96.5
Specific Gravity	2.28	2.12	2.88	2.81
Surface Area, m^2 / kg	486	328	12,000	358
Material Retained on 45μ Sieve (%)	2.20	6.44	Nil	6.50
Bulk Density, kg/m^3	684.0	646	1190	1120
Lime Reactivity	7.50	4.90	16.50	14.50
Particle shape	Irregular	Irregular	Irregular	Irregular
Comparative Compressive Strength %				
168±2 hour	--	--	67	58.0
672±4 hour	104	90	88	70.0

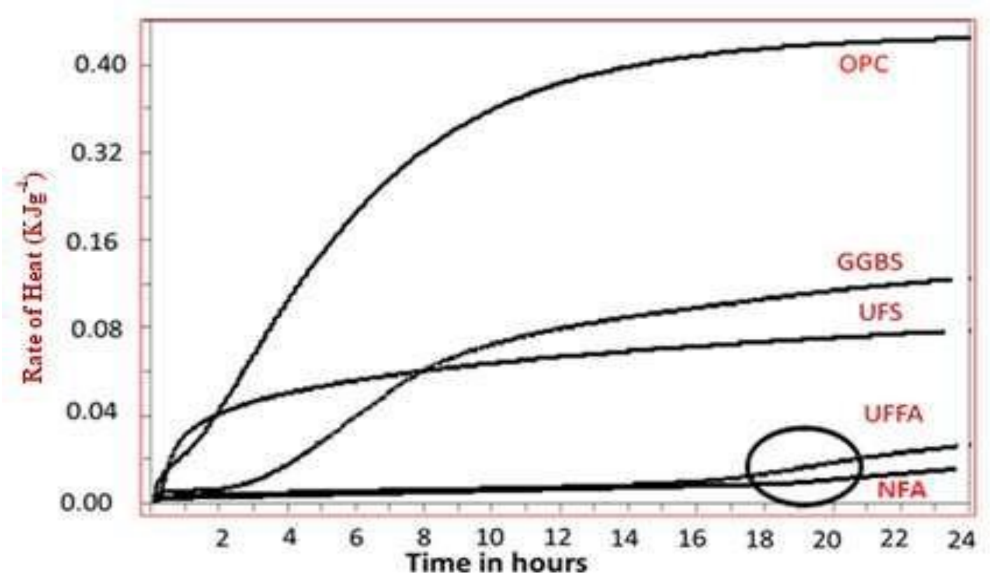
Ref: Dinesh et al.,

Chemical composition

Parameters Tested	UFFA	NFA	UFS	GGBFS
Reactive Silica	36.38	21.12	35.22	32.10
Total Silica (SiO_2)	65.62	55.98	36.22	33.80
Alumina (Al_2O_3)	22.92	27.44	18.60	17.36
Reactive Alumina(r- Al_2O_3)	10.18	11.64	13.82	17.80
Iron Oxide (Fe_2O_3)	4.98	5.94	0.86	1.36
Calcium Oxide (CaO)	1.88	4.82	35.40	38.30
Magnesium Oxide (MgO)	0.86	1.38	6.87	7.38
Sulphur Trioxide (SO_3)	0.08	0.28	0.02	0.02
Insoluble residue (IR)	96.74	88.92	0.62	0.23
Sodium Oxide (Na_2O)	0.33	0.39	0.20	0.21
Potassium Oxide (K_2O)	0.80	0.92	0.80	0.72
Loss on Ignition (LOI)	0.48	1.34	Nil	Nil
Titanium Dioxide (TiO_2)	0.14	0.18	0.08	0.10
Phosphorous pent oxide (P_2O_5)	0.27	0.36	0.22	0.24
Manganous oxide (Mn_2O_3)	0.14	0.13	0.11	0.22
Activator ratio of pozzolana and slag				
Reactive Silica/Al_2O_3 ratio	1.59	0.77	1.84	1.85
Total Silica/Al_2O_3 ratio	2.84	2.04	1.94	1.95
Total Ca/Al_2O_3	0.08	0.18	1.90	2.20
Ratio of Na/Al	1.40	1.52	1.54	1.46

Ref: Dinesh et al.,

Heat evolution during early alkali activation period of geopolymers

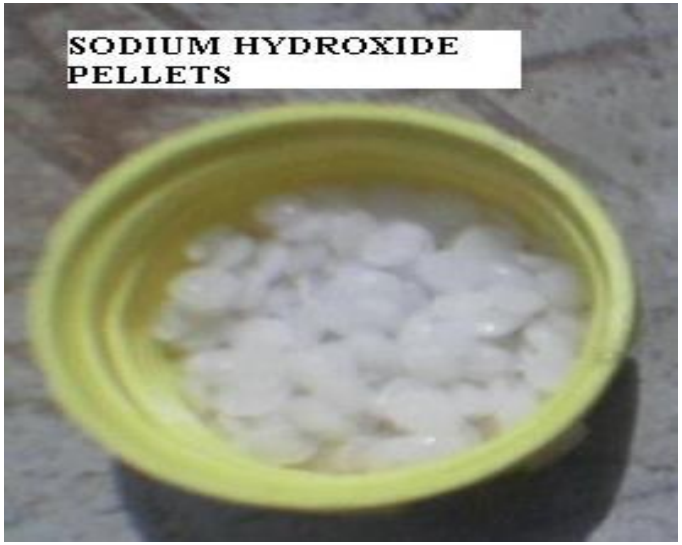


Development of heat in early reaction of reactive silica based geopolymer composites of alkali-activated NFA, UFFA, GGBFS, UFS and hydrated OPC for 24 hours.

Observations

- Heat Evolution in OPC is Very High
- Heat Evolution in GGBFS is Moderately high
- Heat Evolution in UFS is Moderately high
- Heat evolution in UFFA is low
- Heat evolution in NFA is very low

***Alkaline liquid*: sodium hydroxide and sodium silicate solution, used as alkaline liquid.**



Sodium silicate(Gel form)

Alkali Activator Solutions(AAS):

1. Sodium hydroxide (NaOH)

Physico-chemical properties of NaOH

Sl. No	Parameter	Test Results	Parameter	Test Results
1.	Appearance	White colour solid	Specific Gravity	1.690
2.	Solubility in aqueous media	111g/100 ml	Density	2.1 g/cm³
			Purity	99.98 %
3.	Basicity (p Kb)	-2.42	Iron (Fe_2O_3)	0.001
4.	Heat of solution	44.12 kJ/mole	Alumina(Al_2O_3)	Nil
5.	Molar mass	39.9972 g/mol	Carbonates($CaCO_3$)	1.80
6.	Melting point	318°C , 591 K	Lead	0.02

2. Sodium silicate

Na Concentration of AAS at 10Molar.

Sl. No.	Alkali metal ion (M) present in AAS	Na
1.	Ratios of weight	1:1
2.	Molar Ratio	2.50
3.	Metal Type	M-Na_2SiO_3
4.	Mol .mass of M_2O	60
5.	Mol. mass of Silica	60
6.	Percentage of M_2O	15.2
7.	Percentage of SiO_2	33.6
8.	Percentage of Solids	38.2
9.	Density, g/mL	1.61
10.	$[OH^-]$ mol /L	7.72
11.	pH Value	12.62

View of water glass (Sodium silicate) used in the experimental study- Water Content 2

MIX PROPORTIONING OF GPC

B.V.Rangan (Curtin Univ) has carried out significant research on Geopolymer Concrete mixes, short and long term properties.

The guidelines for mix design was:

- Ratio of sodium silicate solution-to-sodium hydroxide solution, by mass, was fixed at 2.5 for most of the mixtures.
- Molarity of sodium hydroxide (NaOH) solution in the range of 8M to 16M.
- A lower water content will result in a stronger mix.

- Ratio of activator solution-to-Fly ash, by mass, in the range of 0.3 to 0.4.

- The quantity of coarse and fine aggregates, 75% to 80% of the entire mixture by mass. This value is similar to that used in Cement concrete.

- Super plasticizer dosage in the range of 0% to 2% of Fly ash, by mass.

- Extra water, when added, in mass.

Parameters governing Geopolymer Concrete Mix

- Molarity of Alkaline Solution and concentration of silicate solution.
- Water to Source material Ratio.
- Duration of Curing.
- Quality and Amount of Fly ash/ GGBS.
- Water content in the mix.

MIX PROPORTIONING METHOD (BMSCE)

Mix proportioning procedure, developed in BMSCE laboratory based on number of trial mixes:

Step 1: The wet density of geopolymer concrete is taken as 2400 kg/cum.

Step 2: Ratio of sodium silicate solution to sodium hydroxide solution is chosen (normally 2.5).

Step 3: Total water content is chosen, considering workability needs, in terms of Percentage mass of total volume of concrete (110 to 140 litres per cum).

Step 4: Total quantity of alkaline solution is then calculated, since the molar ratio of sodium hydroxide solution is known and the percentage solids in sodium silicate solution is also known.

Step 5: Combined quantity of base material (Fly ash and Slag) and aggregate are then determined.

Step 6: Source material (Fly ash and Slag) is assumed as certain percentage of total solids (20-30%).

Step 7: The respective quantities of fine aggregates and coarse aggregates are then determined.

Procedure Adopted:

- ***MIXING***:

➢ *Dry material is mixed initially for 2-3 minutes , and then all the solution is added, mixing is continued for another 3-4 minutes.*

Workability

- *Fresh Geopolymer concrete and mortar, has a good consistency, and is generally cohesive.*

Sticky MIx

CURING OF GEOPOLYMER CONCRETE

Purpose of Curing is two fold –

a. To promote activation; and

b. To preserve water in the mix, from the atmospheric hazards

Curing is generally carried out at elevated temperatures, in the range of 50 to 80 Deg C. Adequate humidity to be ensured or the product is to be insulated to preserve water in the mix

Contd/…

Curing of Geopolymer…

Studies on three different lines have been carried out -

a. ***Curing at elevated temperatures (ensuring humidity), right from the time water and activation source material are added to the base material***

b. ***Curing at elevated temperatures (ensuring humidity or insulation) after about one day of mixing (Curing period 24 hours)***

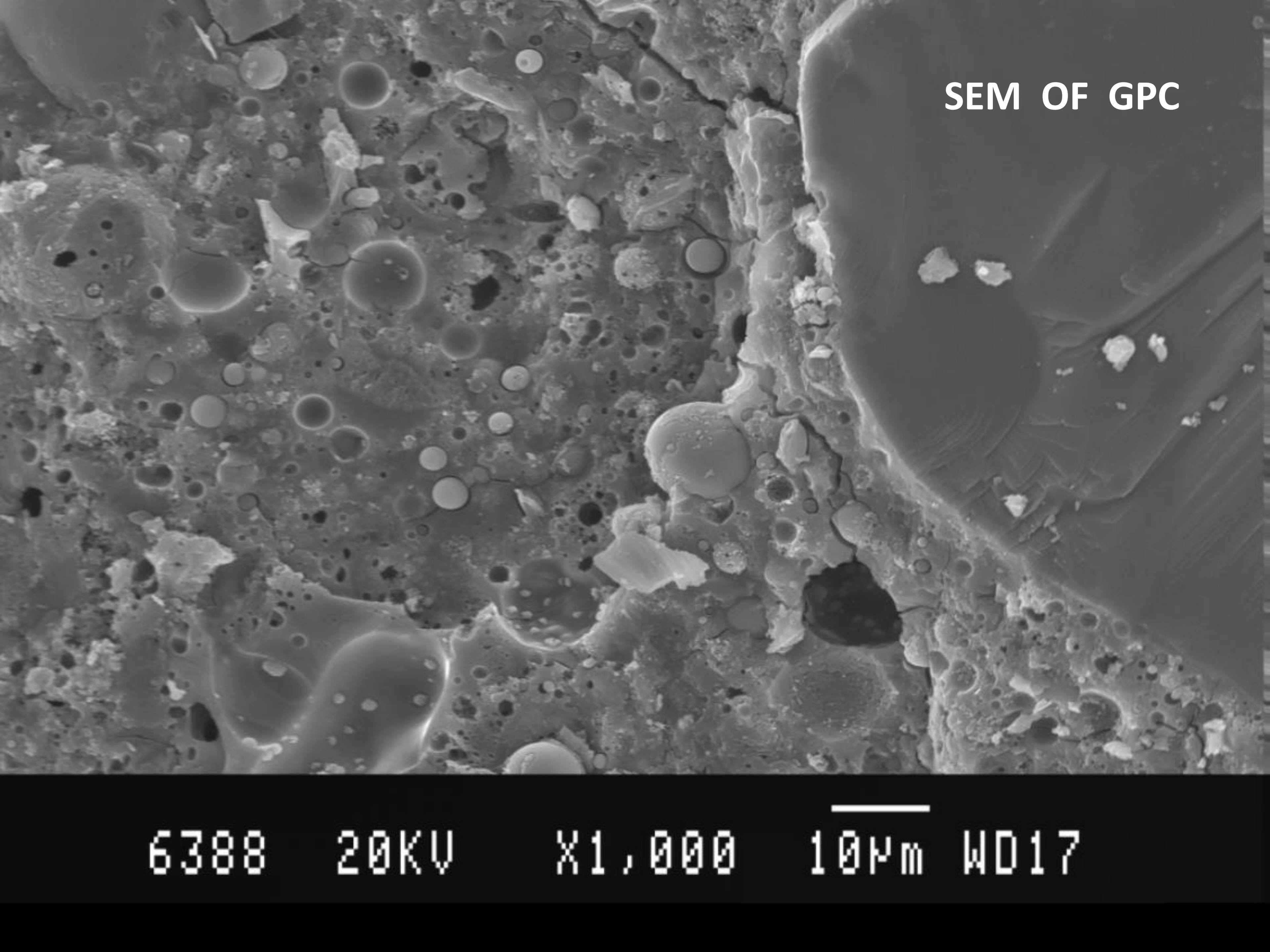
Contd/…

Curing of Geopolymer…

c. ***Curing at normal temperatures in traditional way(7-10 days).***

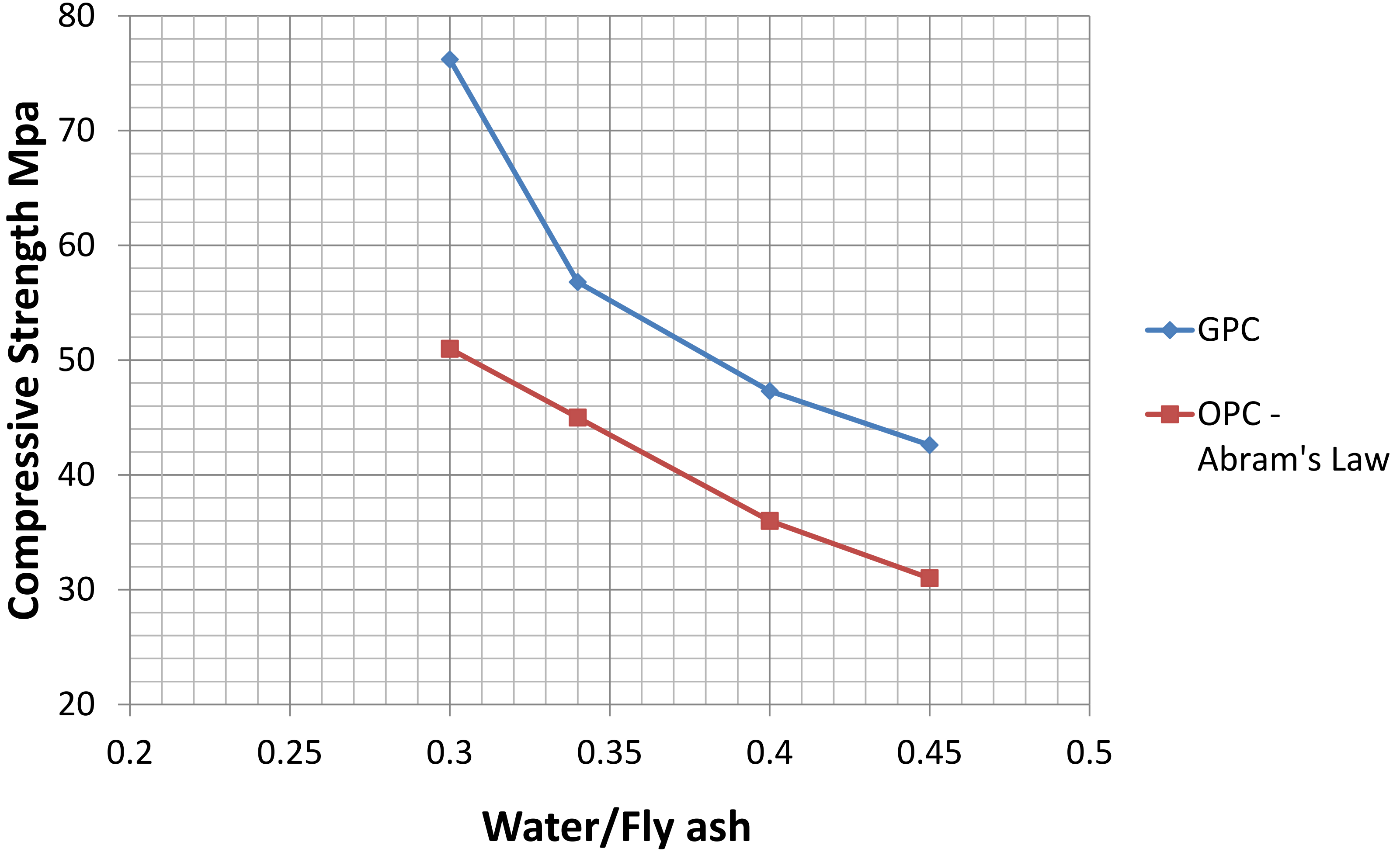
Established curing regime is keeping samples in humid conditions for 24 hours, demoulding and then curing at 60-80 Deg C for 24 hours.

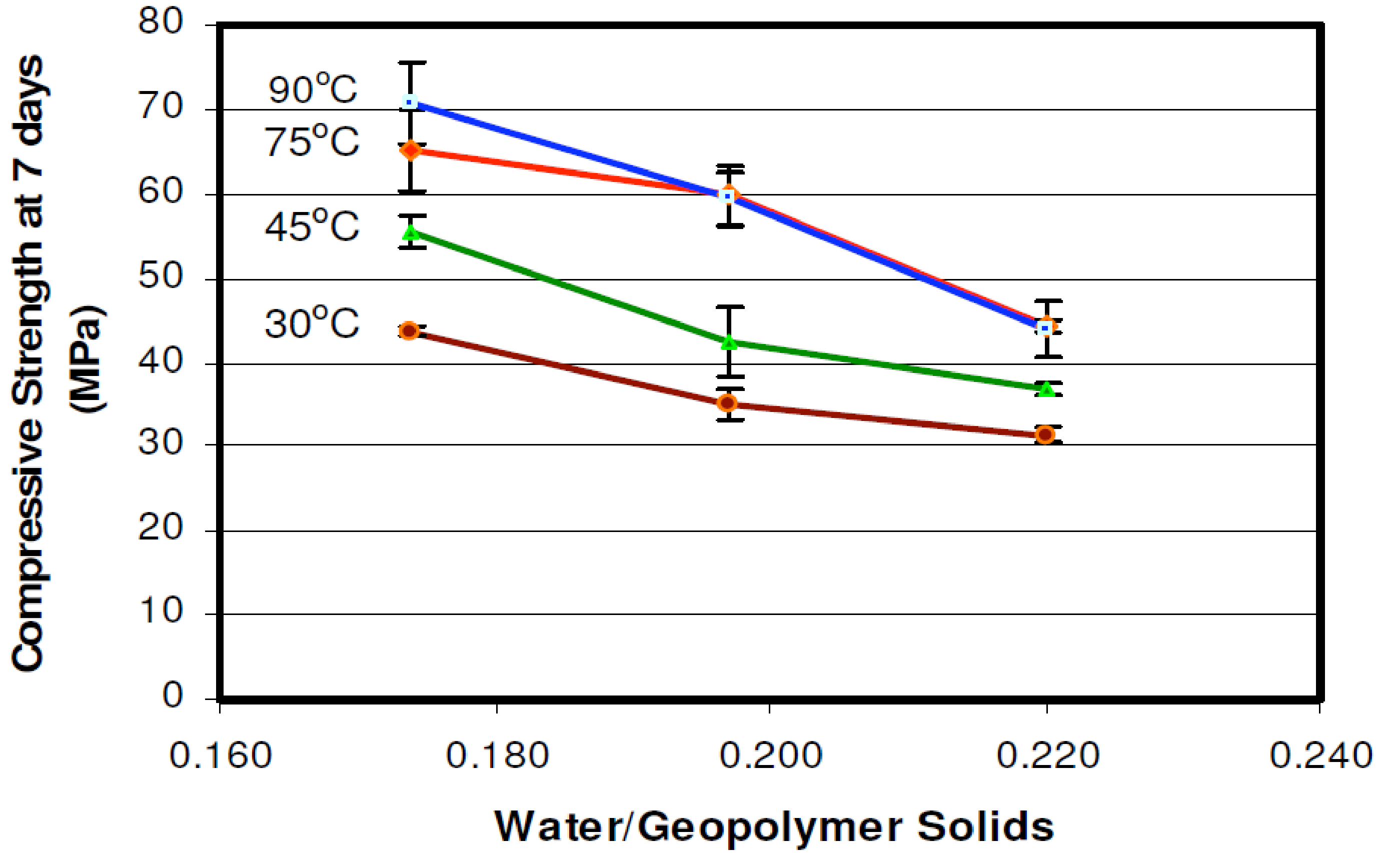
- **Specimens wrapped with coarse plastic cover during curing at elevated temperature in an oven to prevent excessive evaporation**


SEM OF GPC
6388 20KV X1,000 10µm WD17

- Some Properties of Typical GPC Produced in Laboratories using Flyash…

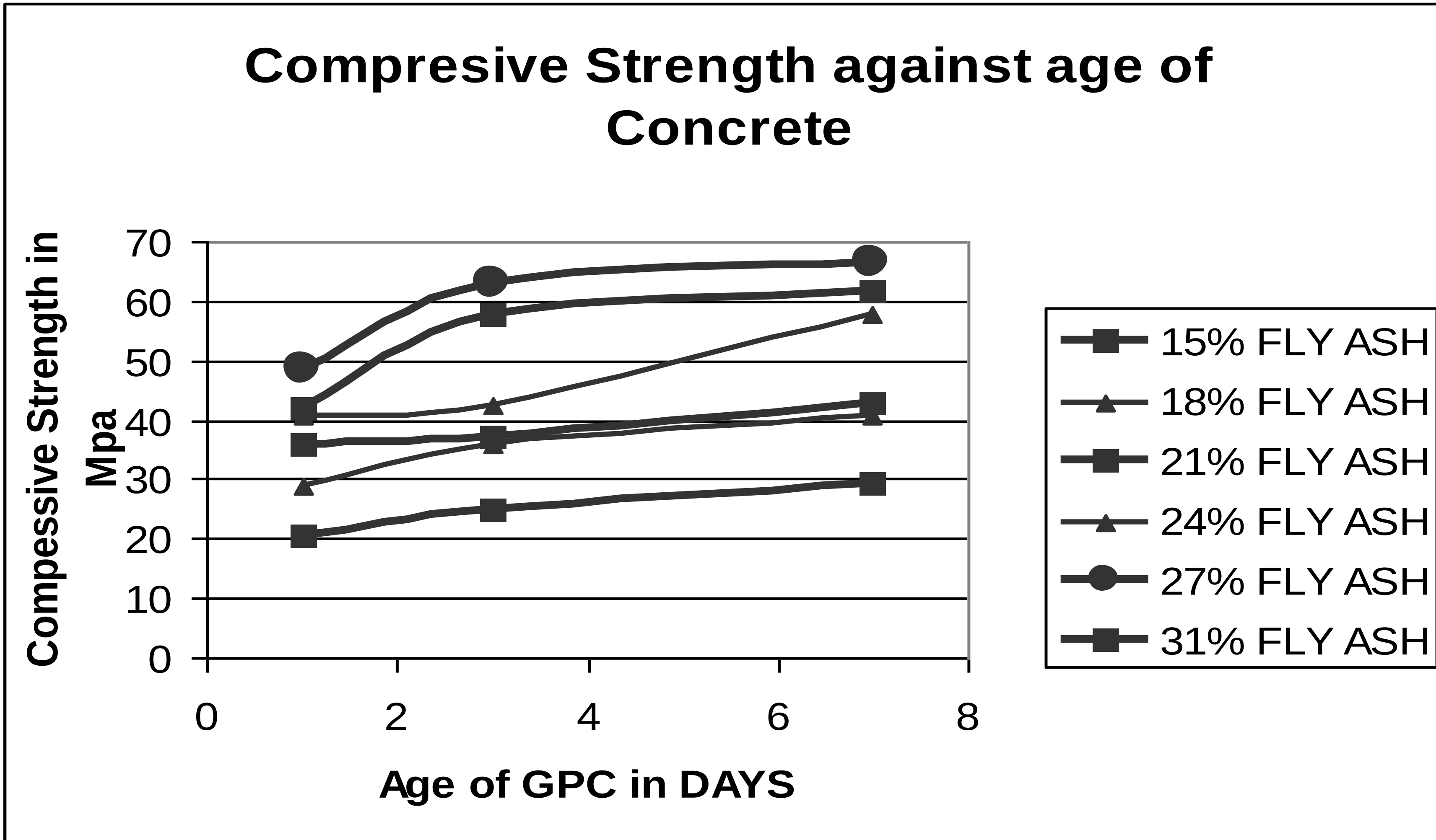
Comparison of OPC and GPC

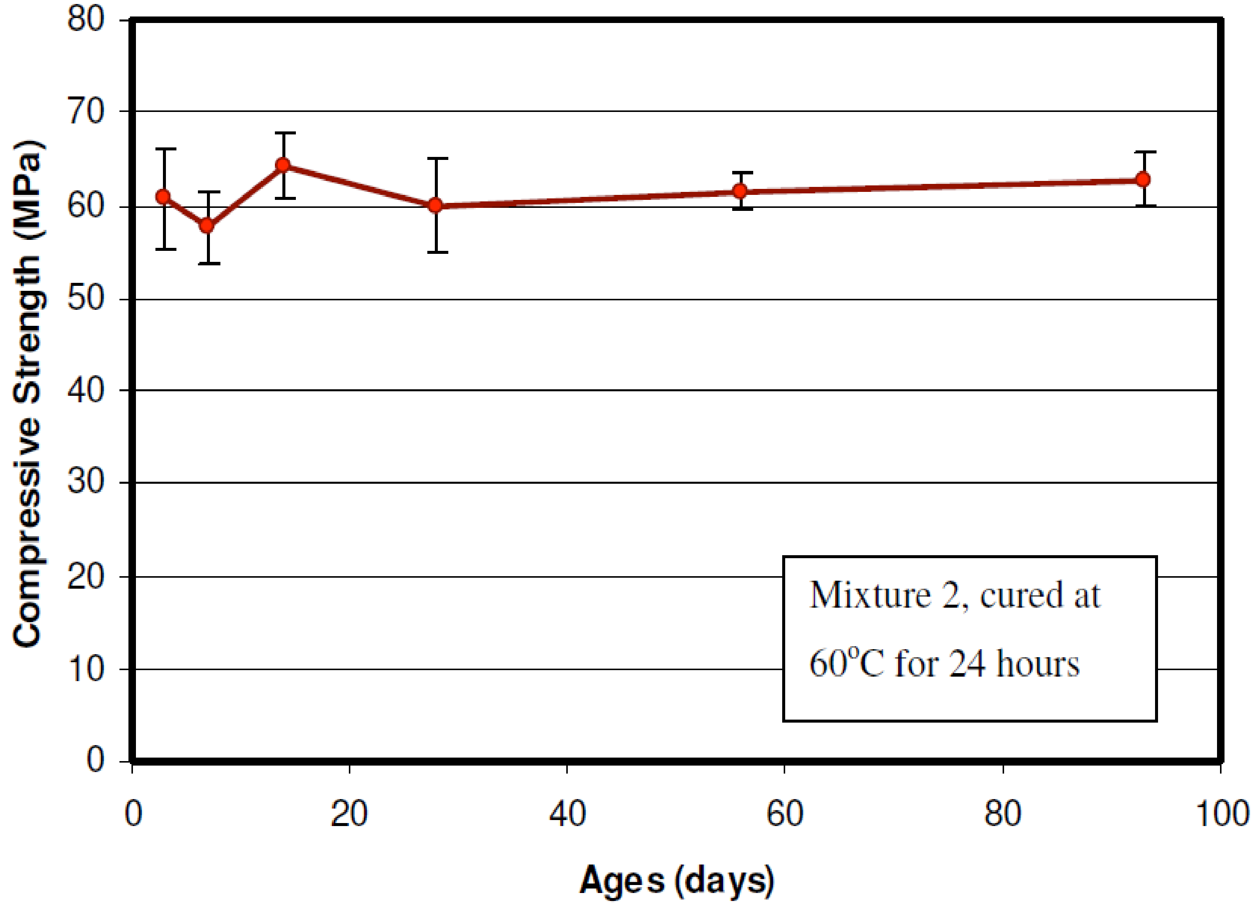




Strength Vs geopolymer solids ratio (Rangan)

Compressive strength of GPC with Age





Comp Strength Vs Age (Rangan)

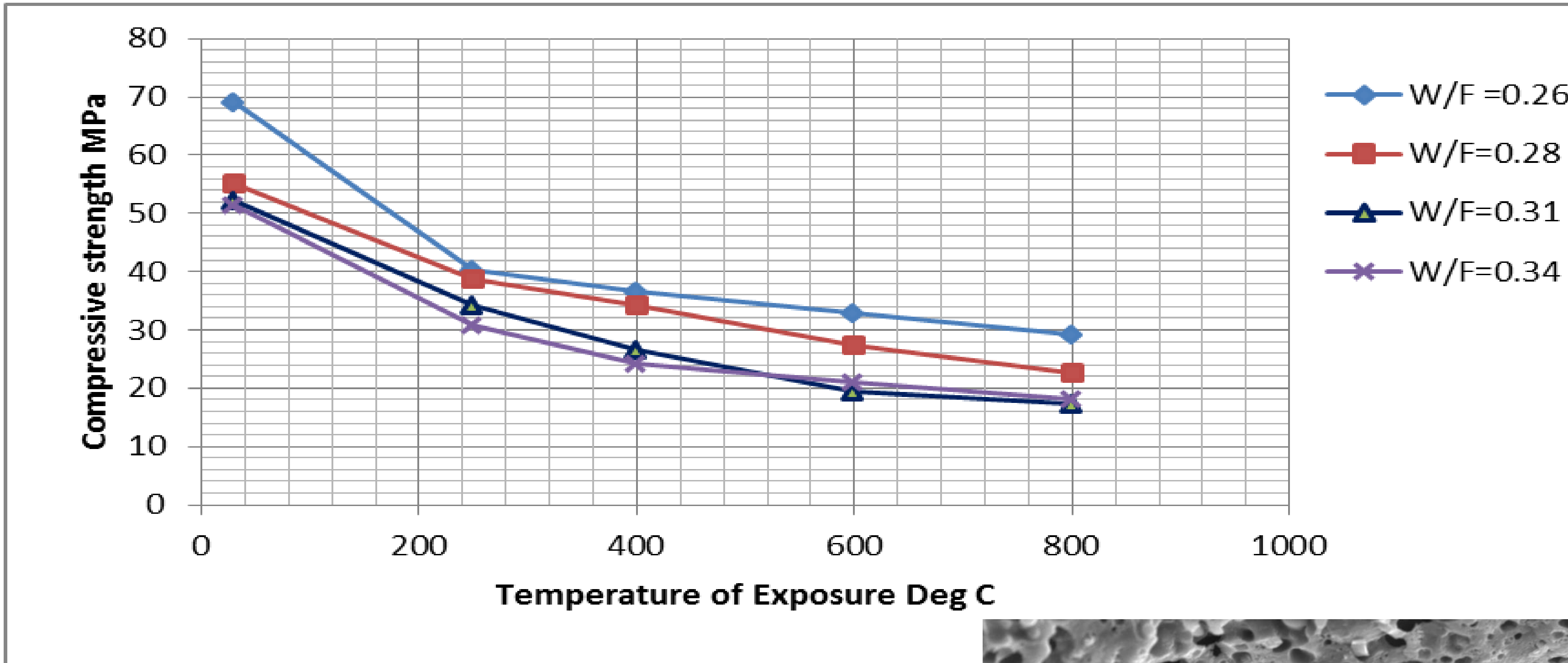
Modulus of Elasticity (Rangan)

f_{cm}	E_c measured (GPa)	E_c (Equation 4.1) (GPa)	E_c (Equation 4.2) (GPa)
89	30.8	39.5 ± 7.9	38.2
68	27.3	36.2 ± 7.2	34.3
55	26.1	33.9 ± 6.8	31.5
44	23.0	31.8 ± 6.4	28.9

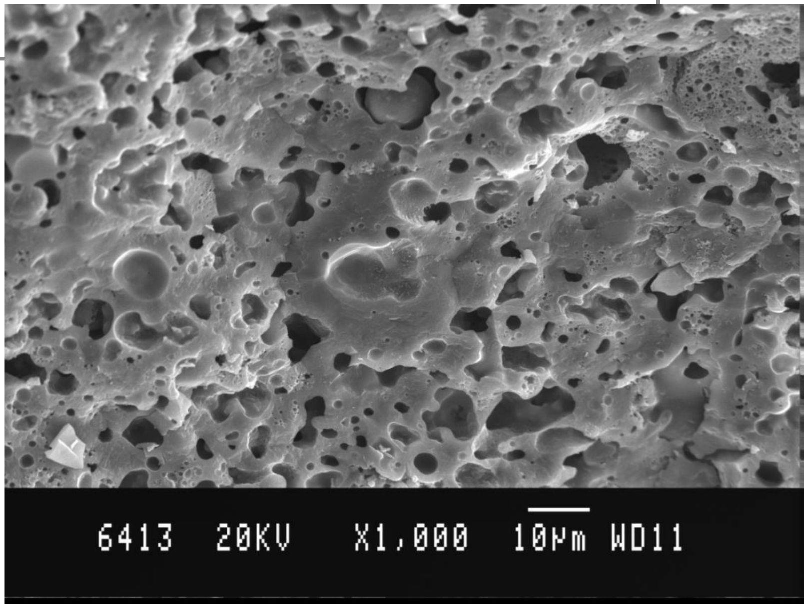
GPC **AUS STD** **ACI STD**

Durability Issues

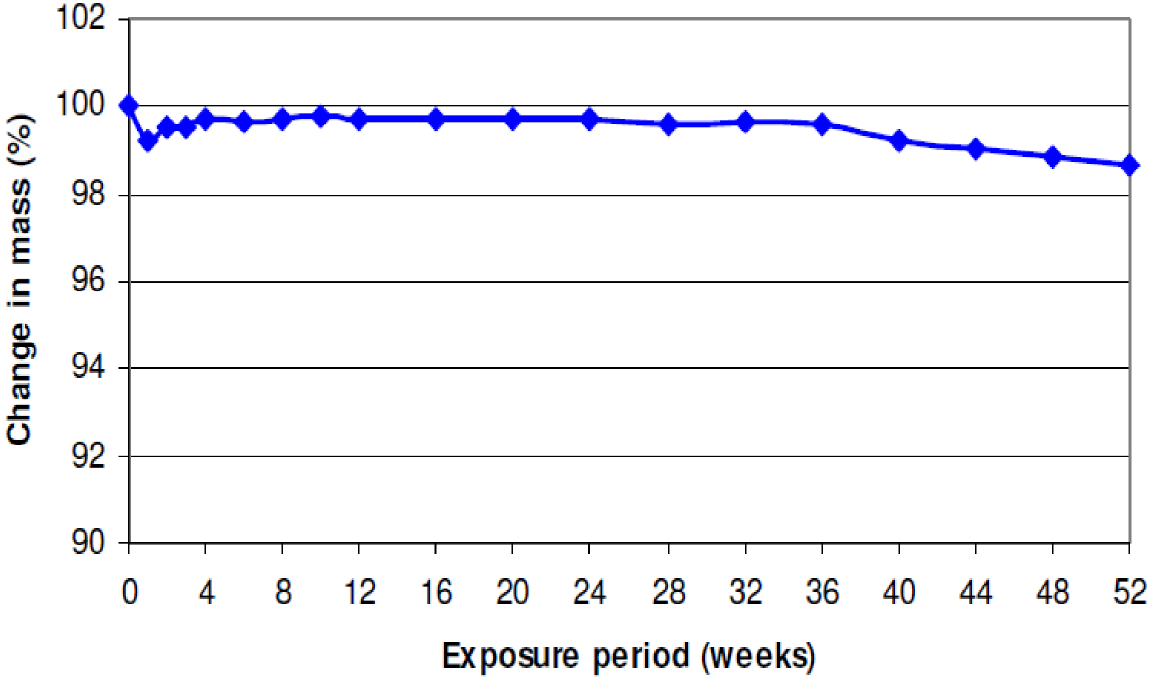
- *Resistance to Elevated Temperature*
- *Sulphate Resistance*
- *Acid Resistance*



GPC EXPOSED TO ELEVATED TEMPERATURE

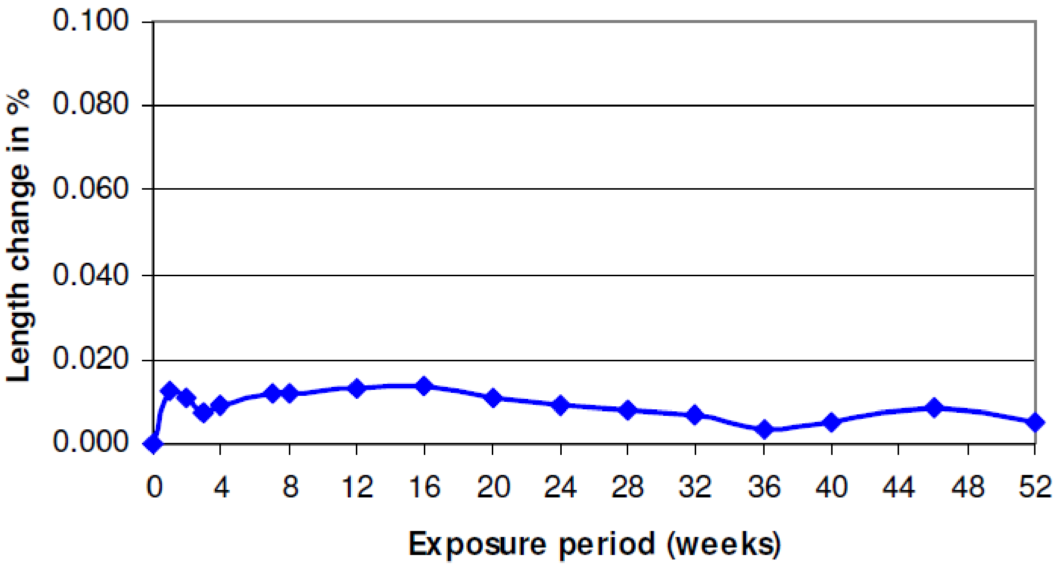


RESISTANCE TO ACID ATTACK



Change in Mass of Geopolymer Mortar Cubes Exposed to 1% Concentration of Sulfuric Acid Solution

ACID RESISTANCE OF GPC



Change in Length of Geopolymer Concrete Specimens Exposed to Sodium Sulfate Solution

SULPHATE RESISTANCE OF GPC (< 0.5%)

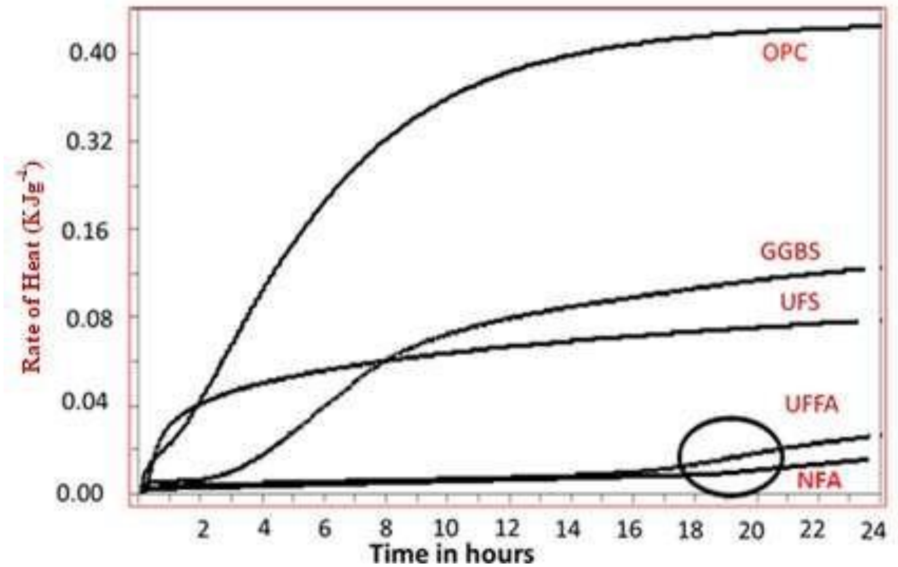
The Research Studies have established geopolymer concrete as an excellent alternative to Cement Concrete with:

- **Similar mix design procedures.**
- **Comparable short term and long term Properties.**
- **Low drying shrinkage.**
- **Excellent resistance to sulphate attack.**
- **Good acid resistance.**

GPC is a durable concrete for aggressive environment.

GPC WITH FLY ASH AND GGBS

- *It is possible to combine the use of Fly ash and GGBFS in Geopolymer concrete.*



- *The reactions may involve both hydration as well as geopolymerisation, which are complimentary to each other.*

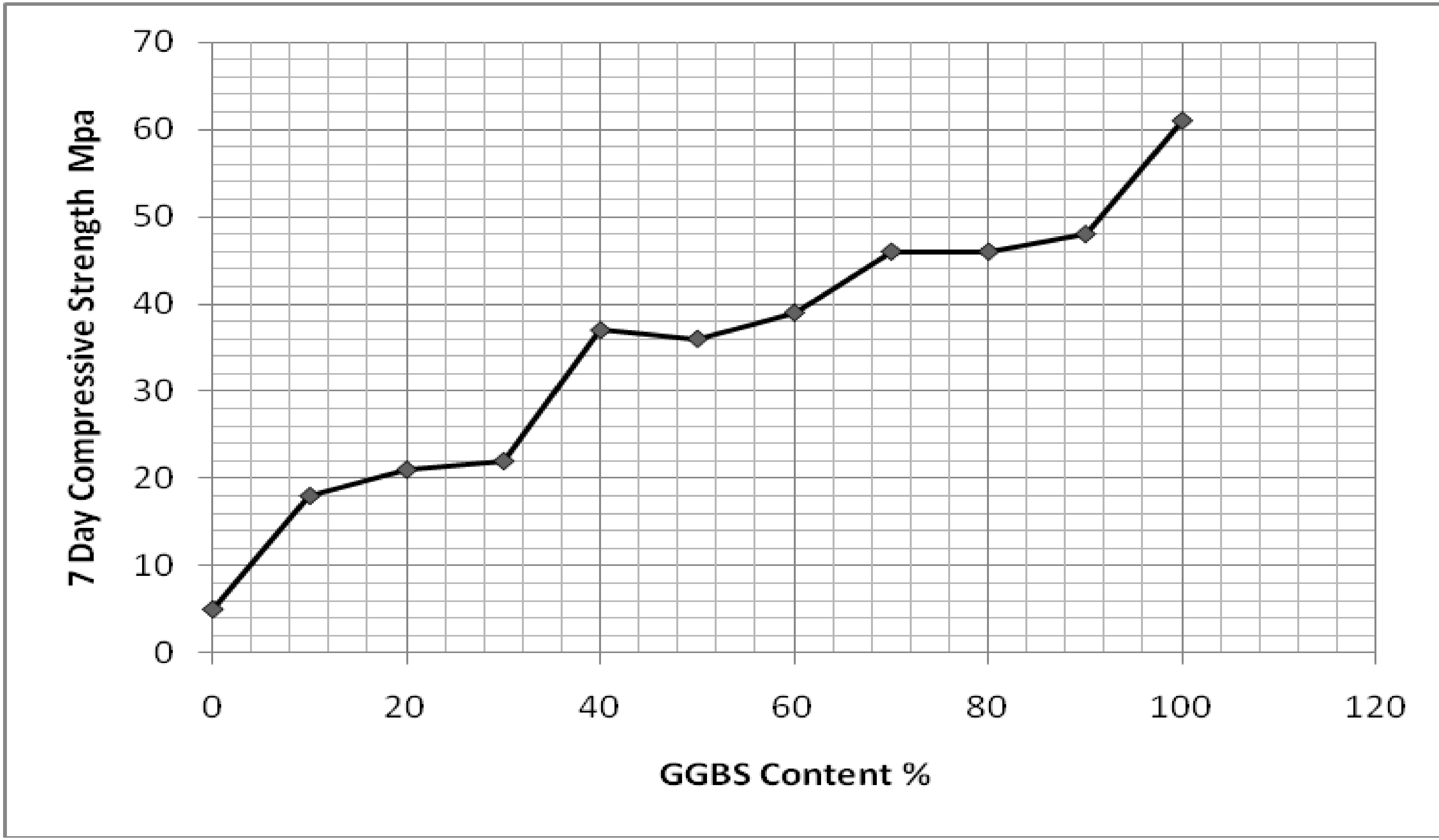
- ***During hydration, the heat produced by the exothermic reactions is useful for geopolymerisation to proceed and the alkaline environment provided by the alkaline solutions will help in enhancing the hydration.***

- *Further, the presence of calcium ions is believed to improve geopolymerisation when alkaline solutions of low concentrations are used in the mix.*

Such a concrete which does not require elevated temperature curing and also water curing will be a promising alternative to tropical countries like India, which is blessed with good ambient sun dry conditions during most part of the year when average temperatures could vary anywhere between 25 to 35^{0}C, across the country.

GPC WITH FLY ASH AND GGBS

Sample No	Proportion (%)		Fly ash kg/cum	GGBFS kg/cum	Fine Aggregate kg/cum	Coarse Aggregate kg/cum	Alkali Solution(kg/cum)	
	Fly ash	GGBFS					NaOH	Na_2SiO_3
1	100	0	423	0	744	947	82	204
2	90	10	380	42	744	947	82	204
3	80	20	338	84	744	947	82	204
4	70	30	296	126	744	947	82	204
5	60	40	253	169	744	947	82	204
6	50	50	211	211	744	947	82	204
7	40	60	169	253	744	947	82	204
8	30	70	126	296	744	947	82	204
9	20	80	84	338	744	947	82	204
10	10	90	42	380	744	947	82	204
11	0	100	0	422	744	947	82	204

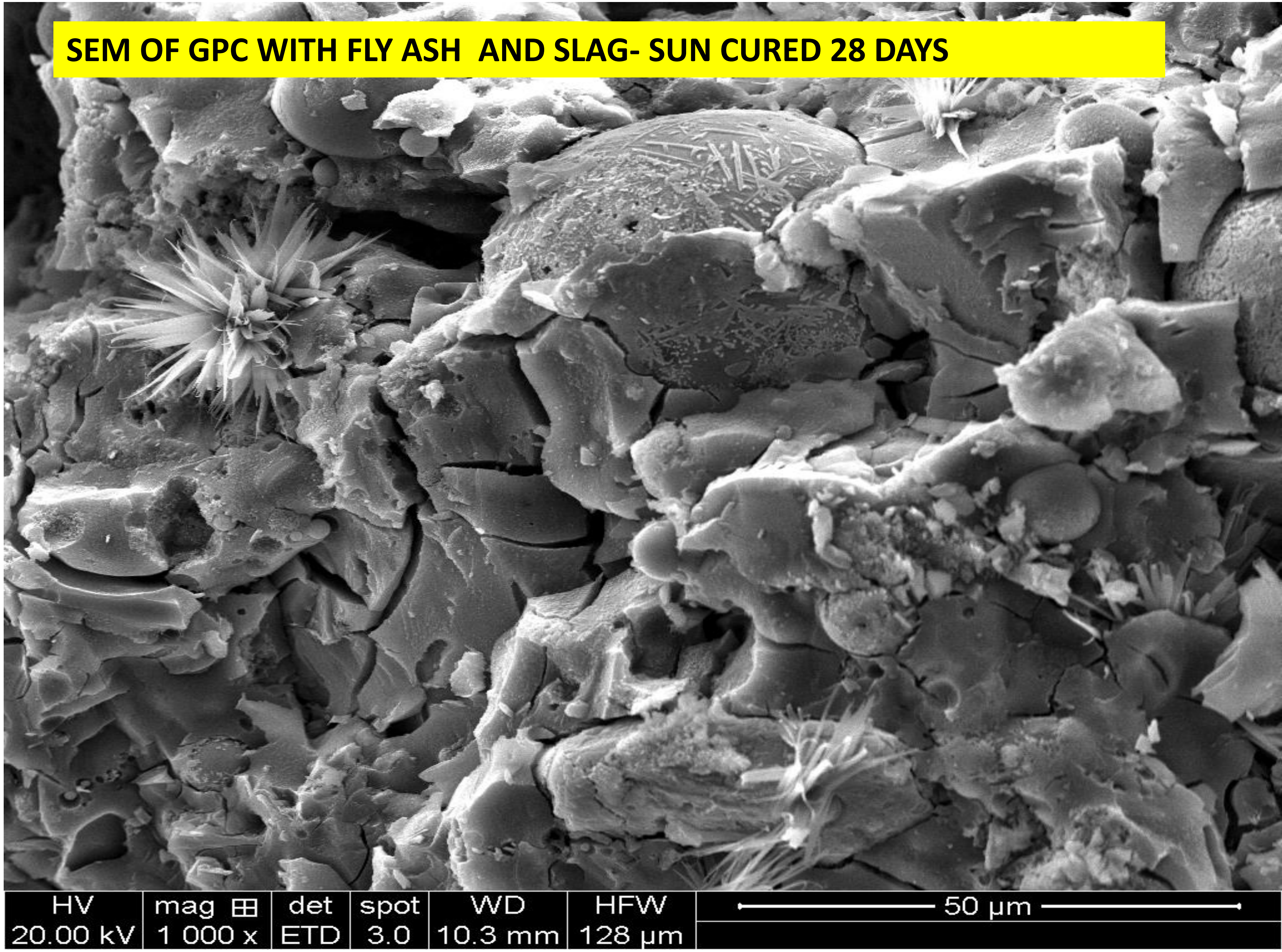


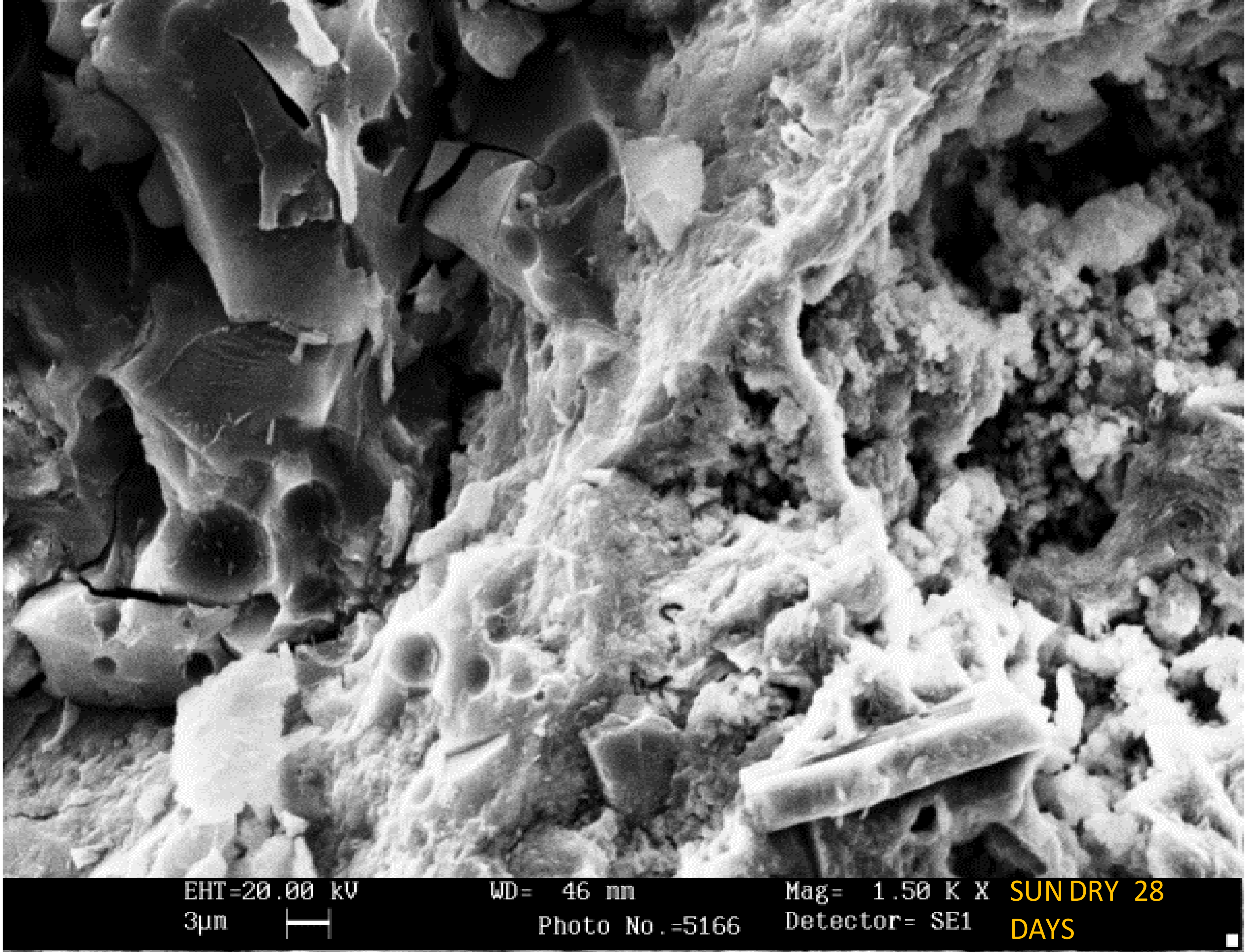
7 Day Compressive Strength Mpa
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
GGBS Content %

-Sun curing for 2 days with mould

Sun curing for 28 days-

SEM OF GPC WITH FLY ASH AND SLAG- SUN CURED 28 DAYS




EHT=20.00 kV
WD= 46 mm
Mag= 1.50 K X
3µm
Photo No.=5166
Detector= SE1
SUN DRY 28 DAYS

STRUCTURAL APPLICATIONS

STRUCTURAL APPLICATIONS

- ***Certain studies on structural strength and behaviour of Geopolymer Concrete (fly ash based) reinforced columns have been carried out at curtin University***

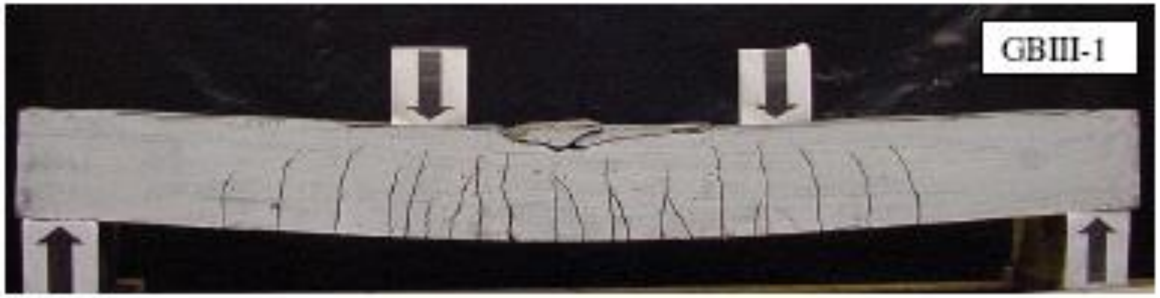
- ***At present, the structural applications are with respect to both precast components and in-place Concrete.***

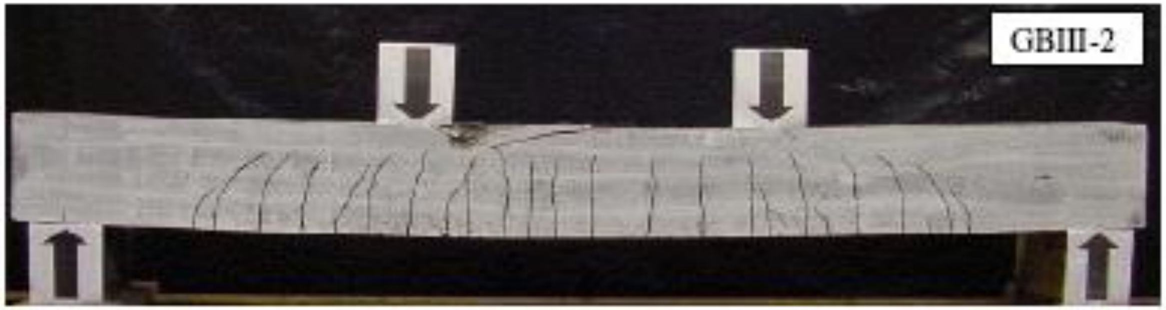
Contd/…

Casting of A Geo-Polymer Concrete Structural element (Typical)

Beams after Demoulding

Column in Testing Machine





Crack patterns and failure Modes of the Testing Beam

PRECAST BOX CULVERTS

STONE ARCHES WITH GEOPOLYMER FERRO CEMENT

Figure 5a: Load testing of a 10 metre precast geopolymer beam.

FIRST APPLICATION OF GPC IN BUILDING. 10.8M x 2.4M WIDE PRECAST FLOOR ELEMENT OF GRADE M40

The Global Change Institute which will be a showcase of sustainable construction.

10.8 metre geopolymer beam with vaulted soffit being craned into position.

2012

Composite pultruded girder and Grade 40 geopolymer deck bridge in Brisbane.

Boat ramp constructed with both precast and in-situ geopolymer concrete.

GPC(M40) WITH GFRP BARS AS REINFORCEMENT FOR SEVERE ENVIRONMENT EXPOSURE - 2011

Placing of pavement for weighbridge using geopolymer concrete.

GPC(M32) PAVEMENT CONCRETE- 2010

ekkomaxx™ is the worlds only, truly green sustainable, high performance cement. It is derived entirely from coal ash and manipulated with CERATECH's line of rapidly renewable proprietary liquid activators to create an extremely versatile and robust cement system.

Concrete produced with the ekkomaxx™ cement system meets or exceeds all ASTM-C-1157 and 1600 specifications, is exceptionally durable and posses superior mechanical properties as compared to ordinary portland cement

The ekkomaxx™ Cement System is an ideal, cost competitive cement option for precast concrete manufacturers as the availability and economics of portland cement production will ultimately undergo change due to recent EPA emissions rulings.

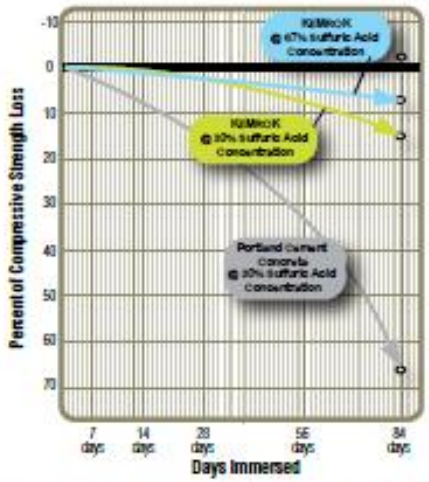
The ekkomaxx™ Production Process

For more information, contact us at: 800-581-8397 info@ceratechinc.com www.ceratechinc.com

Corrosion resistant, precast concrete manhole risers made from non-Portland, eco-friendly cement.

The requirement to coat concrete surfaces with expensive epoxy systems can be eliminated in most cases by utilizing KEMROK™ cement based concrete.

Comparison of Portland Cement Concrete
& KEMROK™ Cement Concrete
Compressive Strength Loss
Through 84 Days Sulfuric Acid Immersion



- **Provide superior corrosion resistance, potentially, without requiring coatings or liners** (See our chemical resistance data)
- **Provide reduced maintenance and repair costs**
- **Superior service life**
- **Has superior compressive, tensile and shear strength versus conventional portland cement based concrete**
- **Reduced shrinkage on cure** (reduces or eliminates issues caused by drying cracking shrinkage)

Produce Corrosion Resistant PRECAST CONCRETE

Offer extended infrastructure life cycles while reducing maintenance costs.

Traditional portland cement based concrete is inherently susceptible to deterioration if not protected with expensive, difficult to install epoxy coatings and/or polymer linings. Improper, inconsistent or discontinuity of these coatings or liners, especially at the joints of precast components creates opportunities for corrosive liquids to damage precast components. This damage leads to costly repair, reduced service life and premature replacement of these structures.

A new, non-portland cement based concrete using 100% flyash from CERATECH called KEMROK™ addresses these issues with a base chemistry that has greatly reduced quantities of calcium hydroxide and calcium silicate hydrates. These two minerals are the main reason why portland cement based concretes are attacked by corrosive acids.

CERATECH Carbon Neutral Cement

CARBON NEUTRAL CEMENT!

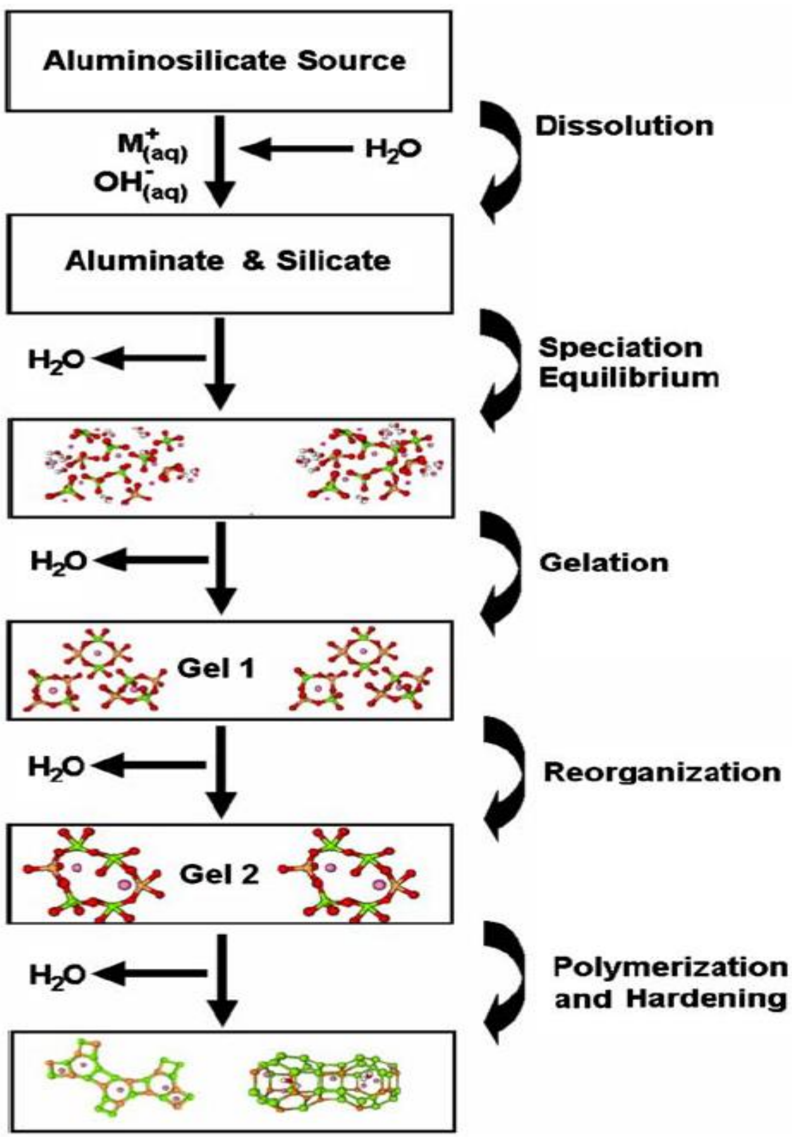
For more information, contact us at: 800-581-8397 info@ceratechinc.com www.ceratechinc.com

E-CRETE, ENVIRO CRETE, etc

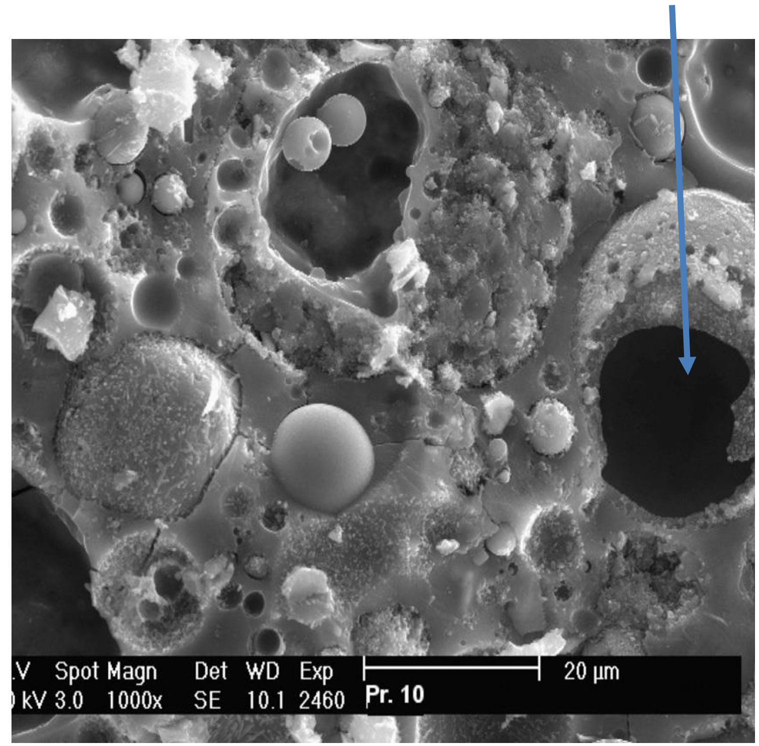
Some Challenges..

- **Role of Water**
- **Sodium Silicate customisation for construction works…**
- Flexural performance..
- Safety ..

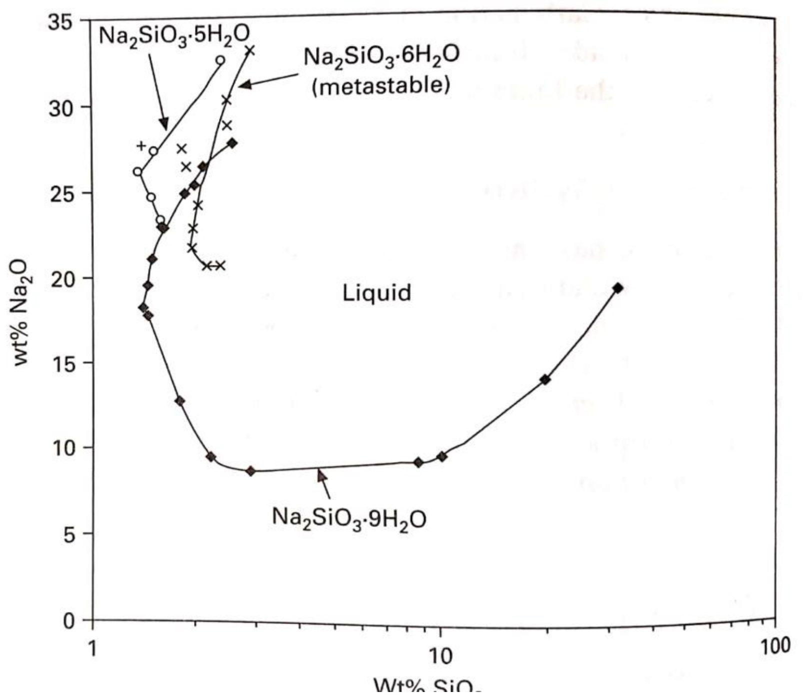
➢**Role of Water**



Water craters



Sodium Silicate



Chemical Composition of Sodium silicate (Available in Market)

LEGEND	% SiO_2	% Na_2O	% H_2O	Grade
A	39.18	17.81	33.9	2.2
B	37.85	14.02	43.81	2.7
C	30.88	9.35	53.73	3.3

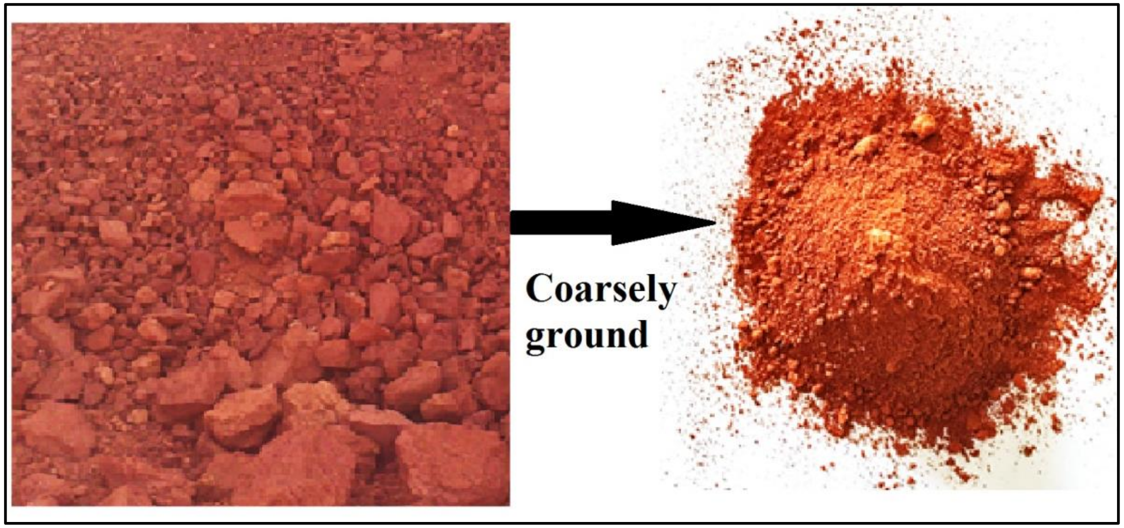
Research Avenues..

- Mining/Industrial waste utilisation in Geopolymers
- Non-thermally activated Clays (Tank Bed soil)
- Immobilisation of toxic wastes in geopolymers

Mining/Industrial waste utilisation in Geopolymers

- Red MUD example….

Characterisation-Red mud



Red mud in the as collected state and then ground to pass through 300-micron sieve

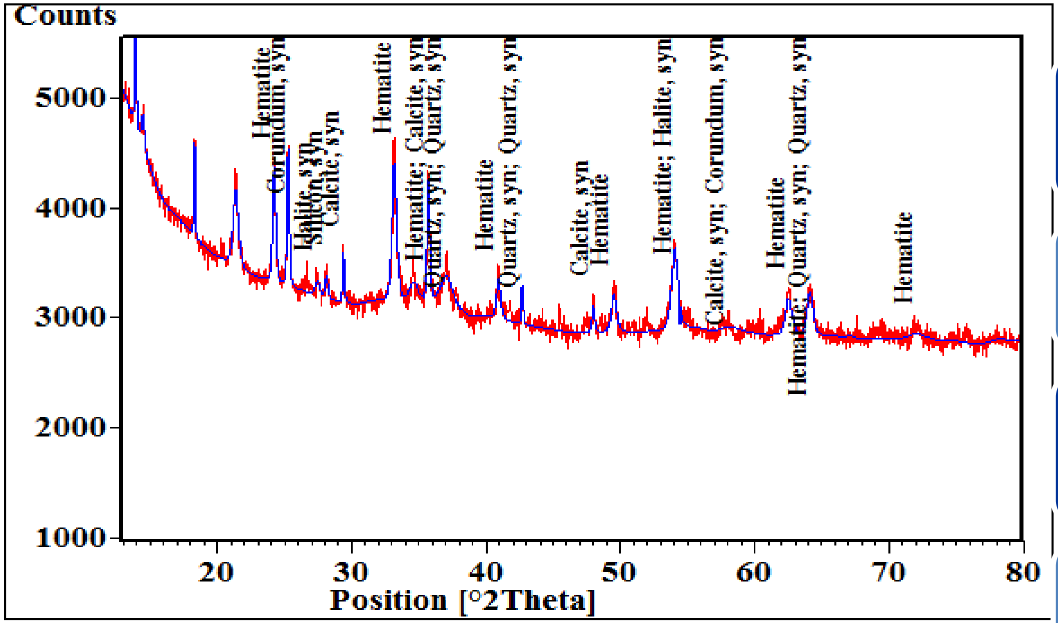
Chemical Composition

SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	TiO_2	P_2O_5	V_2O_5	L.O.I
9.93	18.1	42.9	2.3	5.58	9.03	0.35	0.31	10.5

Properties

Specific gravity	Surface area (m2/kg)	Lime Reactivity (MPa)	pH	Reactive silica%
3.25	33,650	0.95	11.0	1.62

Ref: Smita et al.,



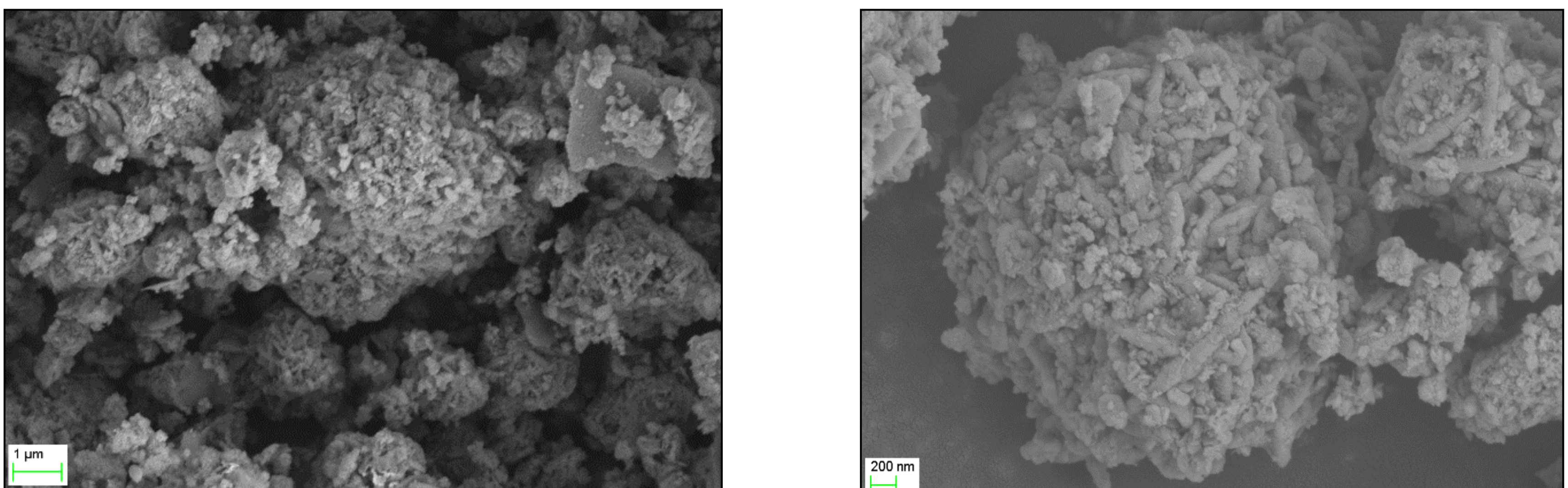
XRD and identified pattern list

From XRD, the main phases present were calcite ($CaCO_3$), hematite (Fe_2O_3), corundum (Al_2O_3), halite (NaCl) and quartz (SiO_2).

Presence of sharp peaks indicated that the minerals were mostly in crystalline phase

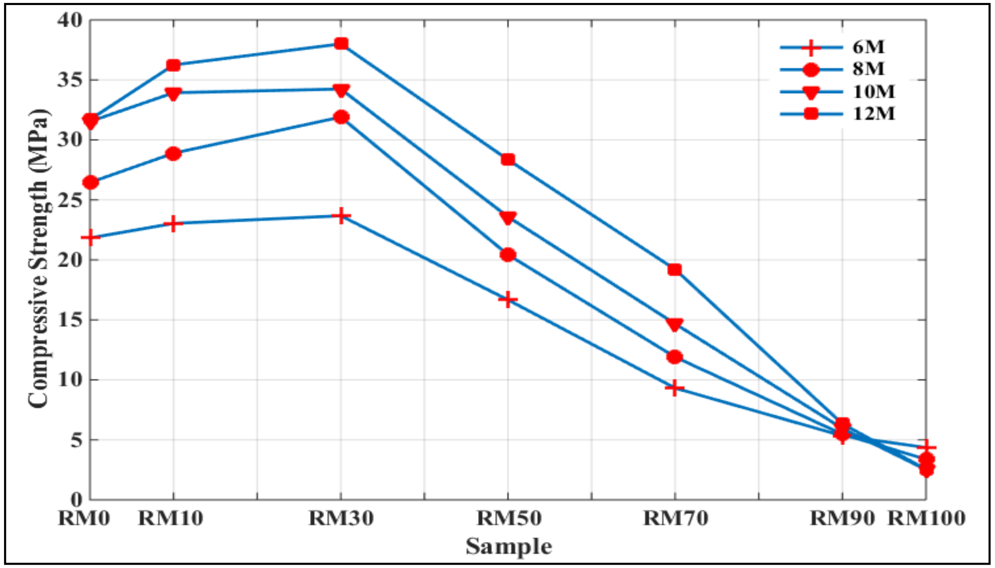
From SEM, the sample consisted of lumps of irregular shapes (hematite), and each lump appeared to be made of much smaller particles

Irregular-shaped crystalline particles of size about 1 µm lay scattered in the image, likely representing quartz crystals



SEM micrographs

Ref: Smita et al.,



Compressive strength of thermally cured geopolymer paste

Specimen	Binder composition (RM : FA : MS)%
RM100	100 : 0 : 0
RM90	90 : 0: 10
RM70	70 : 20 : 10
RM50	50 : 40 : 10
RM30	30 : 60 : 10
RM10	10 : 80 : 10
RM0	0 : 90 :10

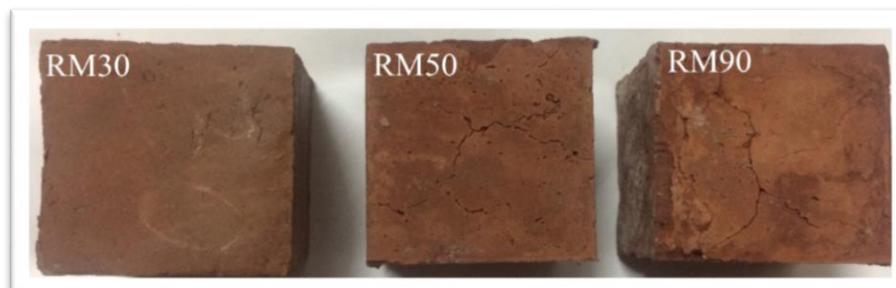
Compressive strength increased with molarity

Optimum of red mud % in the binder was 30%

Red mud contribution to strength

Alkalinity

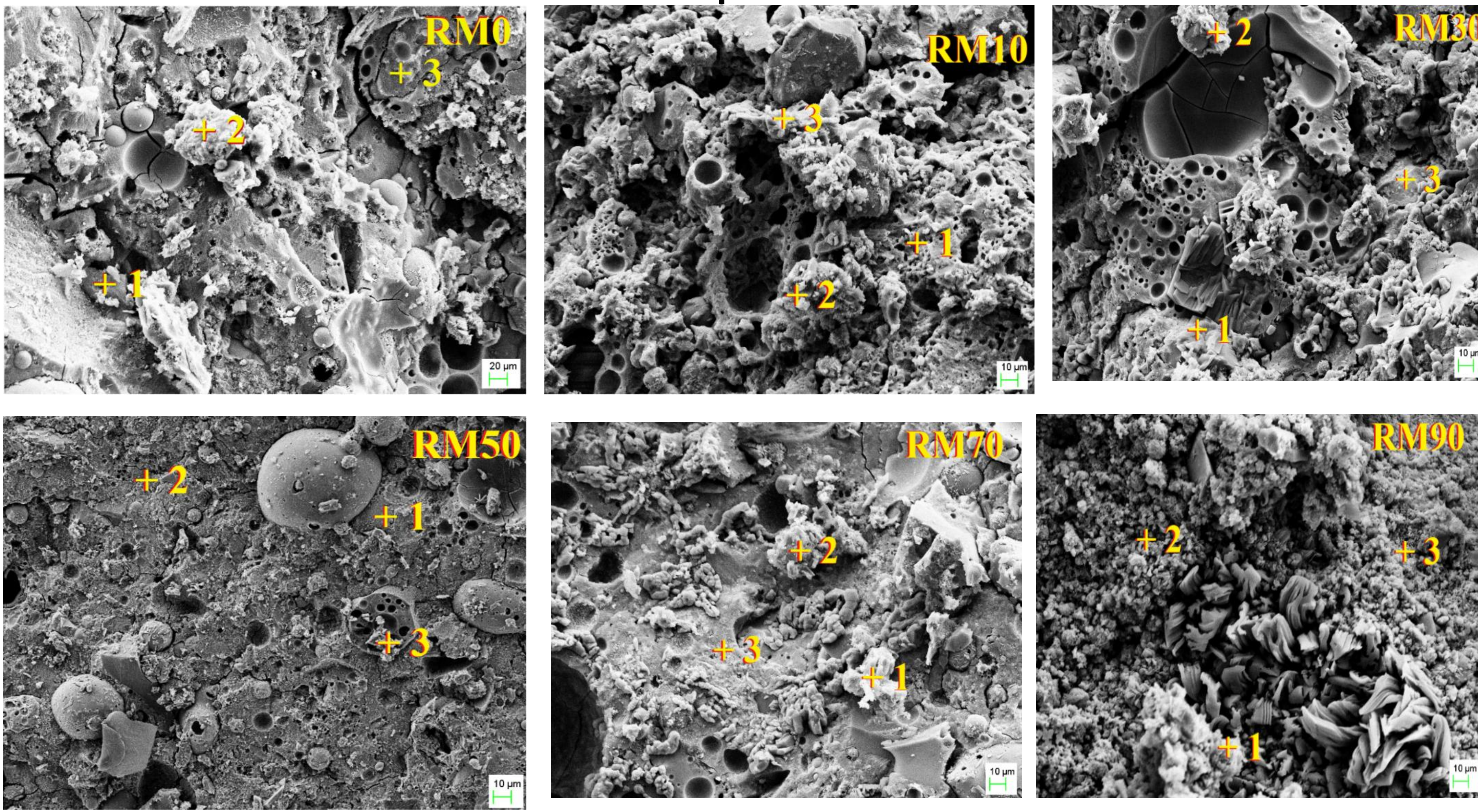
Ultra fine particles act as filler



Thermally cured geopolymer cubes of RM30, RM50 and RM90

Ref: Smita et al.,

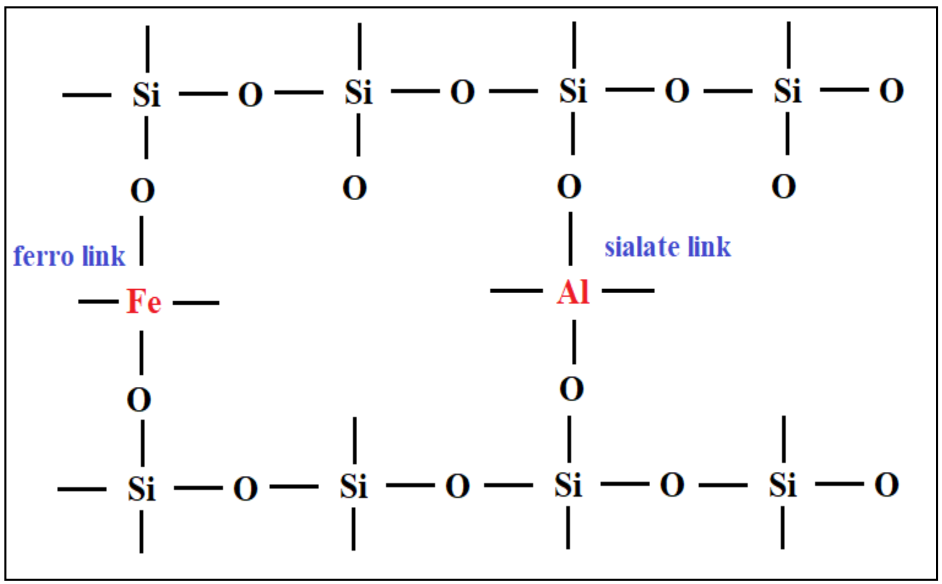
Microscopic Studies



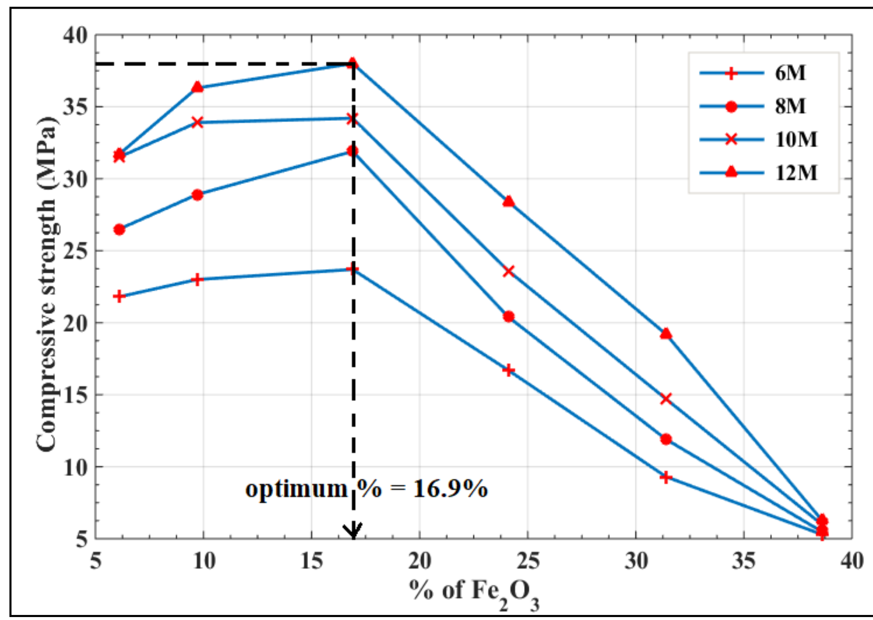
The unreacted phases of fly ash particles and quartz crystals were minimum when red mud % was 30

In RM30 and RM50, iron was traced as part of continuous matrix, thereby hinting the participation of Fe in geopolymerisation

- It was suggested in prior investigations that Fe_2O_3 had certain favourable effect on geopolymerisation
- Davidovits introduced a new type of geopolymer binder called ferro-sialate-based geopolymer cement
- Maximum strength was obtained at 16.9% of Fe_2O_3 that corresponded to RM30



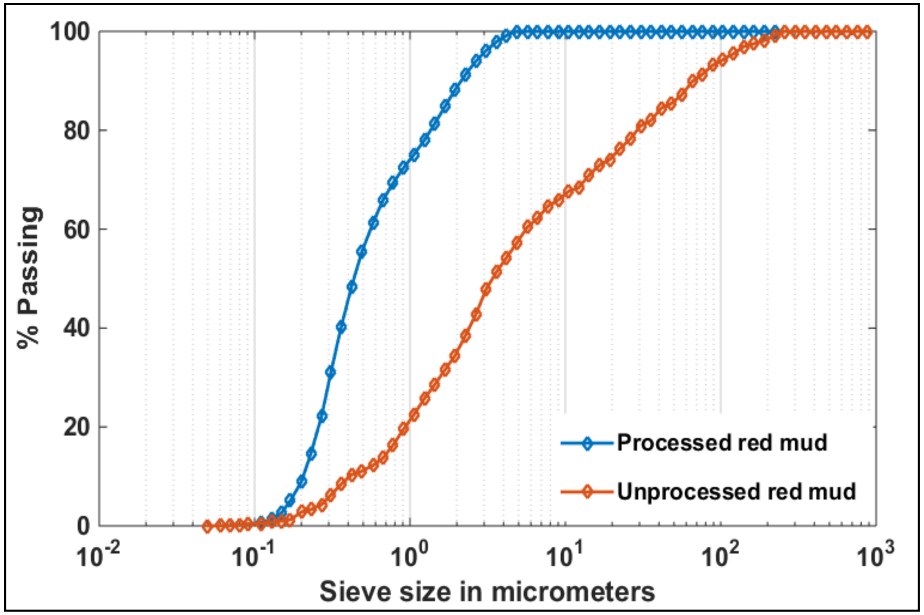
Ferro-sialate geopolymer structure



Variation of compressive strength with % of Fe_2O_3

Ref: Smita et al.,

Characterisation of Pulverised Red Mud



Particle size analysis

Particle size analysis test revealed that processed red mud consisted of ultrafine particles of size lesser than 5 µm

The processing of red mud increased its reactivity with lime from 0.95 MPa to 3.61 Mpa

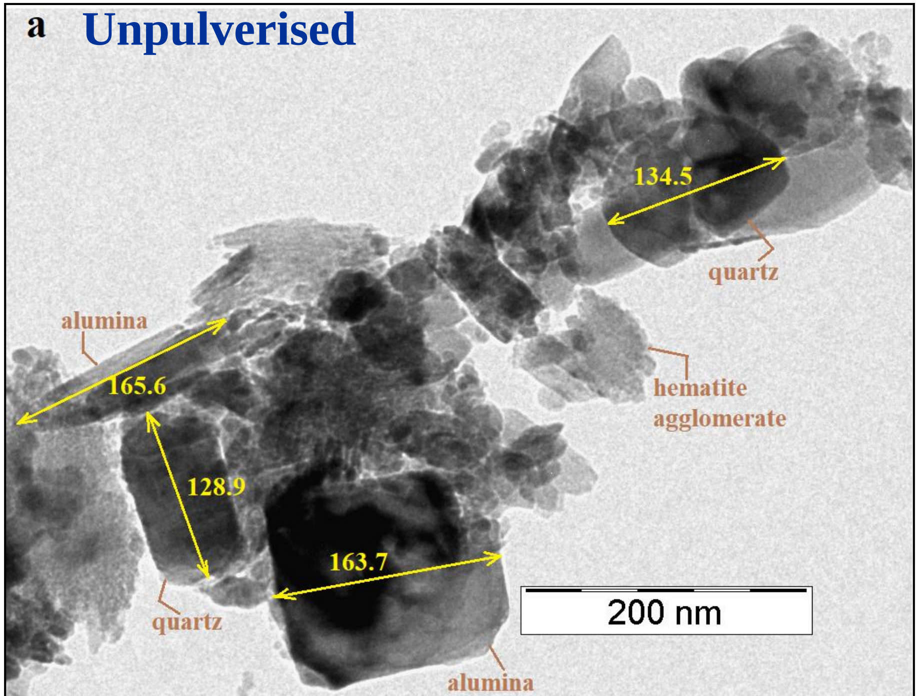
Reactive silica percentage from 1.62% to 5.12%

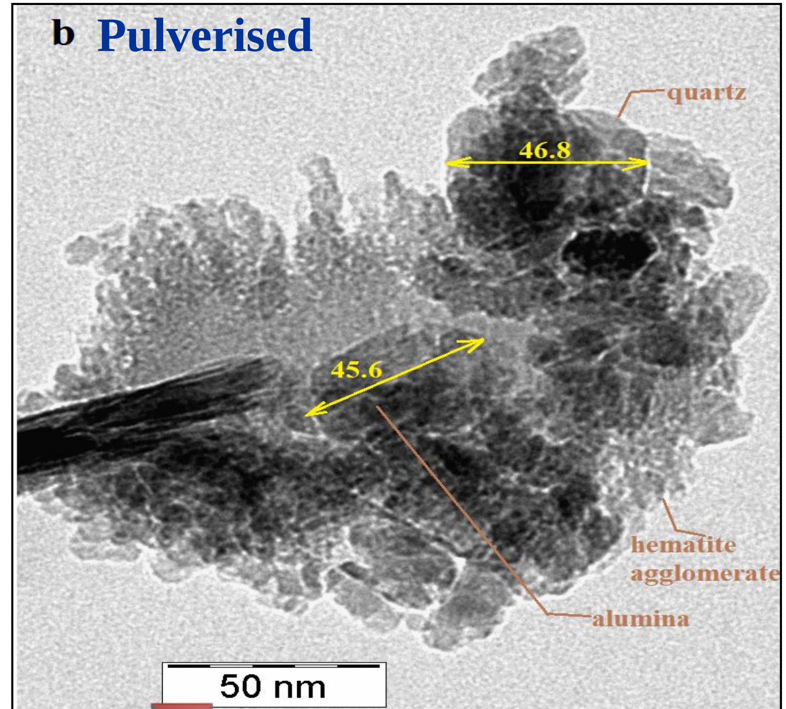
in spite of having 27.12% of reactive silica, the reactivity of fly ash with lime was lower than that of red mud

Properties

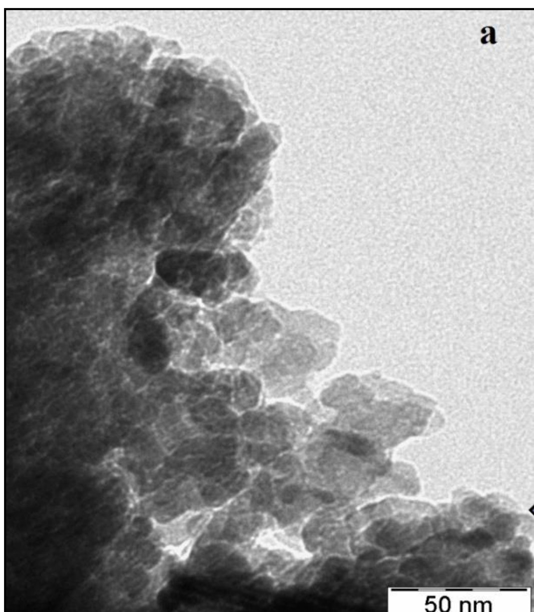
Specific gravity	Surface area (m^2/kg)	Lime Reactivity (MPa)	pH	Reactive silica%
3.2	39400	3.61	10.8	5.12

Ref: Smita et al.,

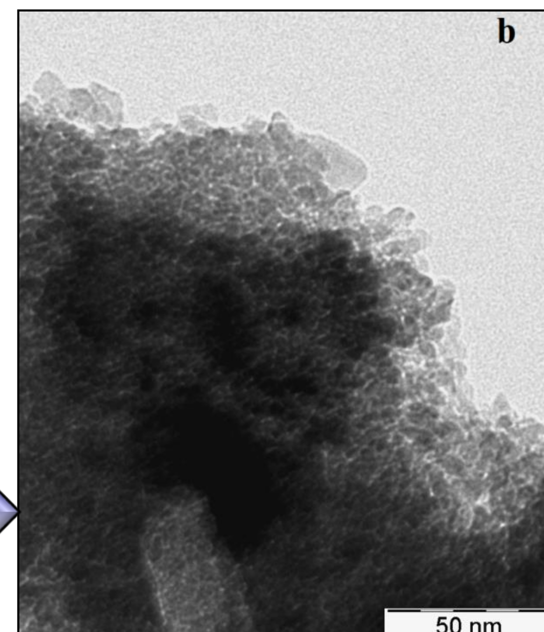


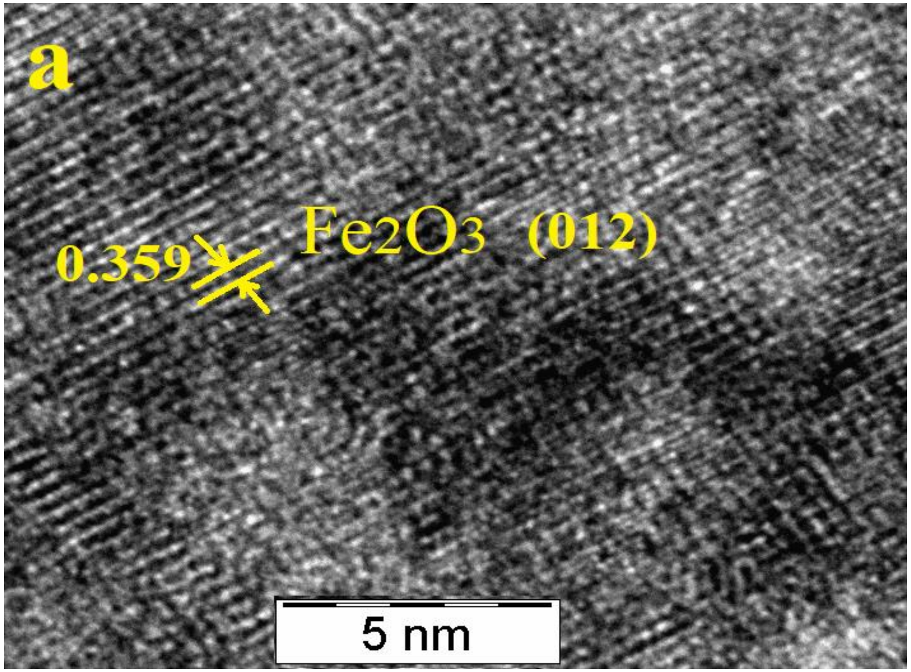


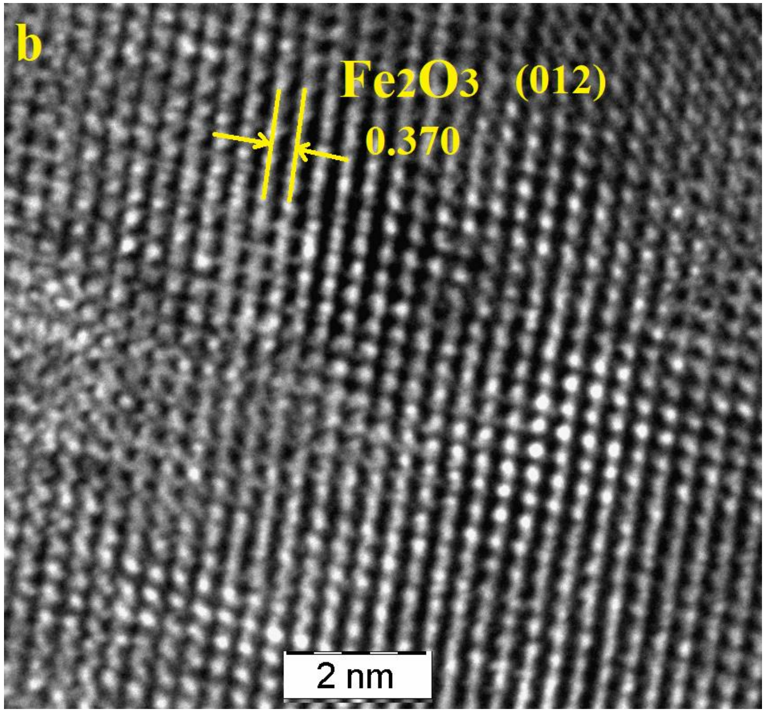
Crystals of quartz and hematite reduced in size after pulverisation



Average-sized particles of around 7 to 8 nm to reduce to about 5 nm





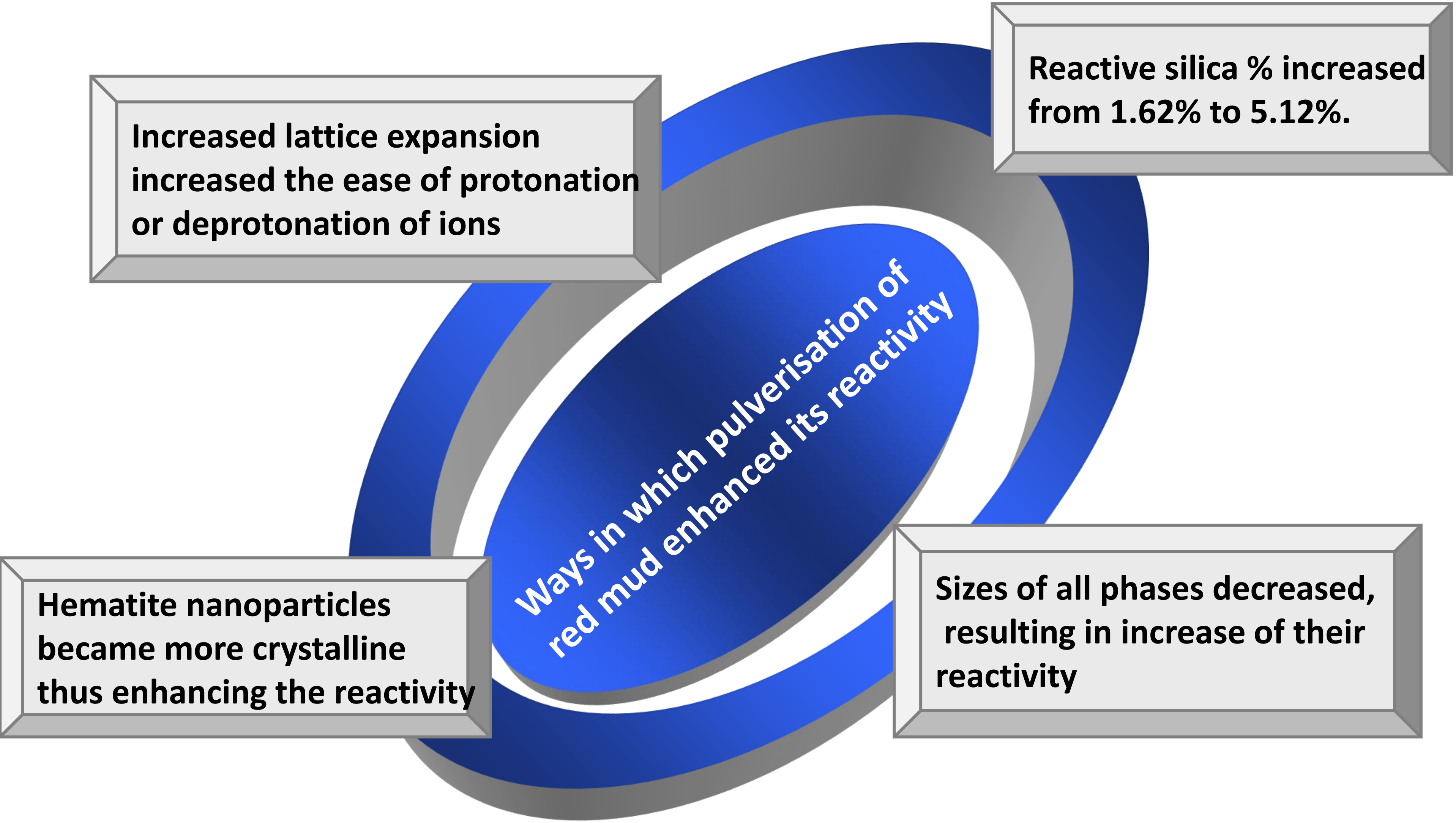


HRTEM and lattice spacing of a) unprocessed, b) pulverised red mud samples

The spacing d between the two lattice planes appeared to have increased after pulverisation

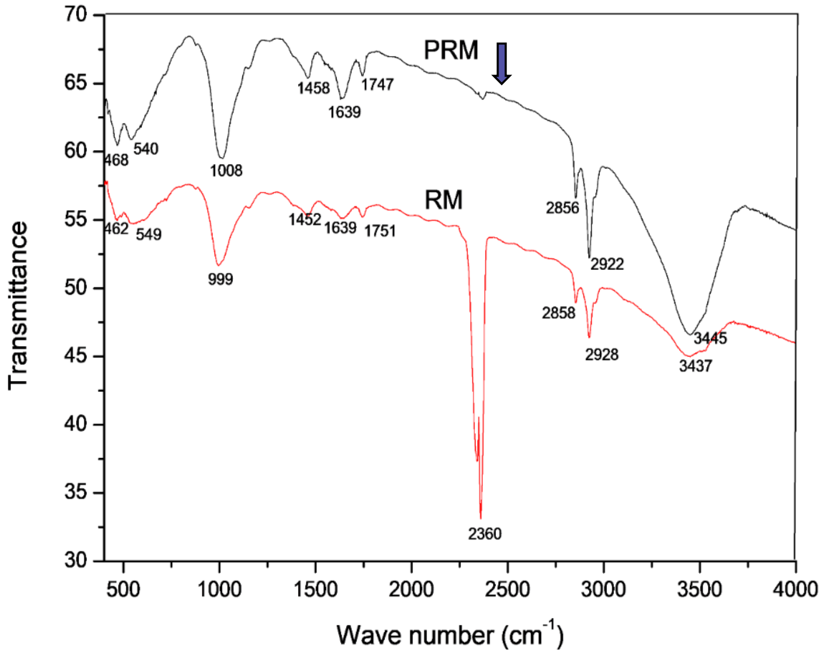
Appearance of ions seemed brighter, which indicated increase in crystallinity which complements the XRD results

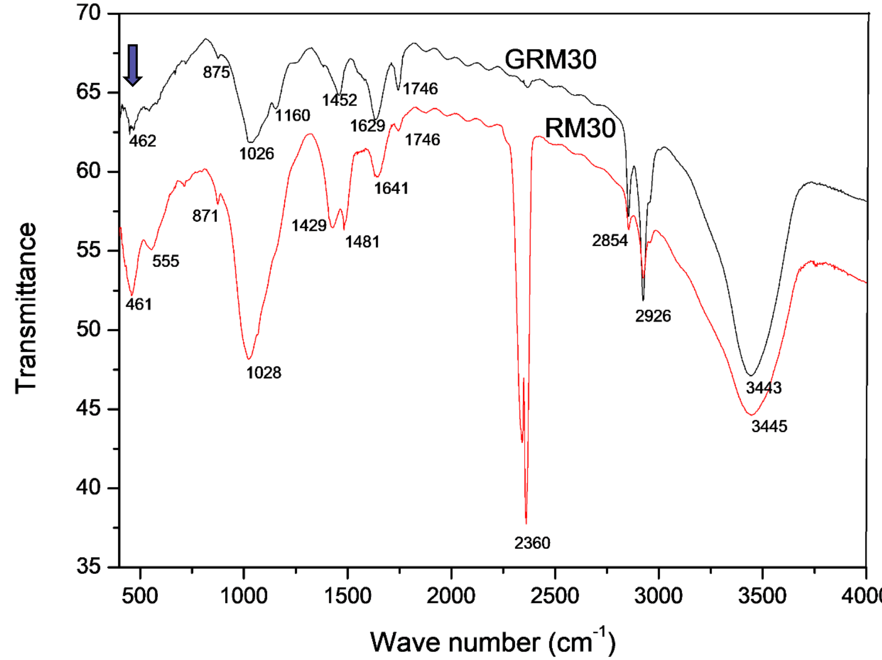
Ref: Smita et al.,

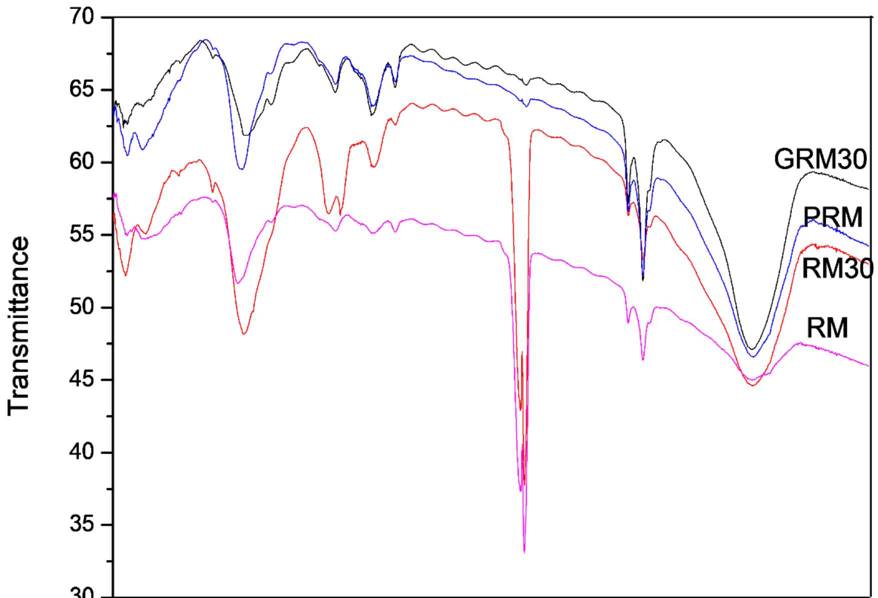


Ref: Smita et al.,

Fourier Transform-Infrared Spectroscopy







Significant reduction of peak at 2360 cm-1 in PRM. The IR at 2360 cm-1 possibly represent the water molecules associated with the ferrihydrite and other hydrate phases of red mud which reduced considerably after pulverisation due to phase transition

GRM30 had only one hematite peak at 462 cm-1 and that too with diminished intensity, this indicated the dissolution of more Fe atoms from the crystalline hematite phase and their participation in the geopolymeric network

Non-thermally activated Clays

- Tank Bed soil…..

Guddaemaranahall i tank bed

Ghati tank bed

Harti tank bed

TBS BEING DRIED AND LUMPS BEING CRUSHED TBS SIEVED THROUGH 2.36MM SIEVE AND STORED

Ref: Jyothi et al.,

Brick powder(BP)

Brick bats → Manually crushed to 40mm → Pulverizer used to crush to 75 micron

- Specific gravity was 2.67.
- 100% of materials passed thro
  75Microns.

Ref: Jyothi et al.,

FLOW TEST

To find the optimum fluid content required for every mix proportions flow test was conducted.

Fresh mix of geopolymer composites

Flow table

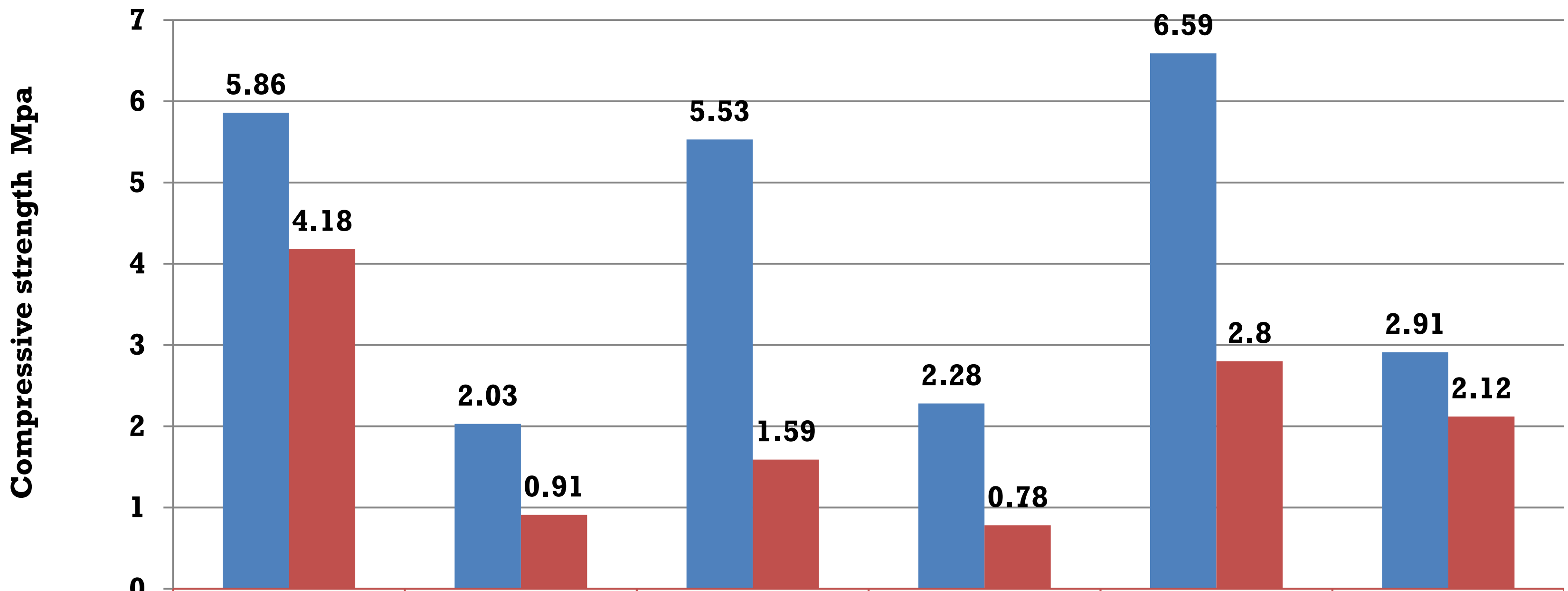
Flow test observation

Ref: Jyothi et al.,

GEOPOLYMER BLOCKS USING TANK BED SOIL & BRICK POWDER

1. **Influence of curing conditions**

CURING EFFECTS ON GEOPOLYMER BLOCKS USING GUDDAEMARANAHALLI SOIL



	LCGUBP7M7D 50:50	LCGUBP7M7D 75:25	P1LCGUBP7M 7D50:50	P1LCGUBP7M 7D75:25	P2LCGUBP7M 7D50:50	P2LCGUBP7M 7D75:25
Ambient Curing	5.86	2.03	5.53	2.28	6.59	2.91
Heat Curing	4.18	0.91	1.59	0.78	2.8	2.12

Ref: Jyothi et al.,


Ingredients used for LPC
Consistence paste
Paste on glass plate
Briquettes
Kiln constructed for burning
Fuel arrangement
Kiln sealed for burning
Kiln during burning process
Thermocouple used for material temperature measurement
Unloading of material
Ref: Jyothi et al.,

Production of Bricks

Dry mixing of materials

Wet mixing of geopolymer composite

Placing of fresh composite

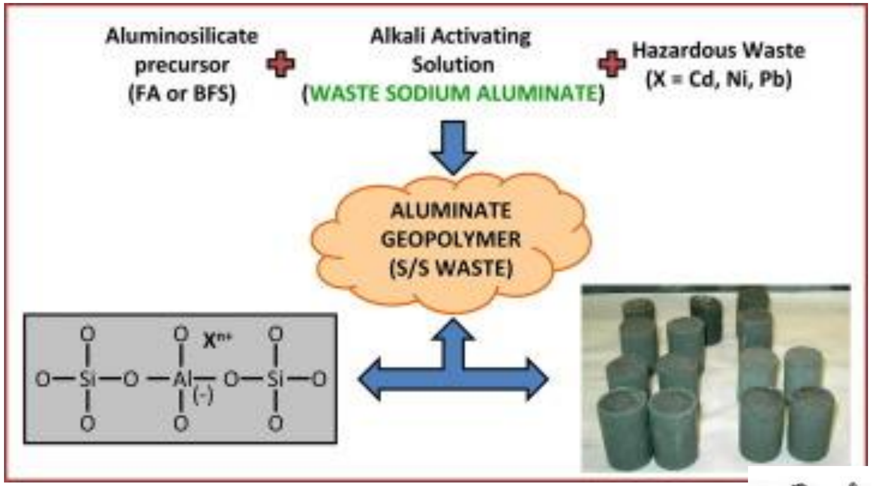
Cast brick

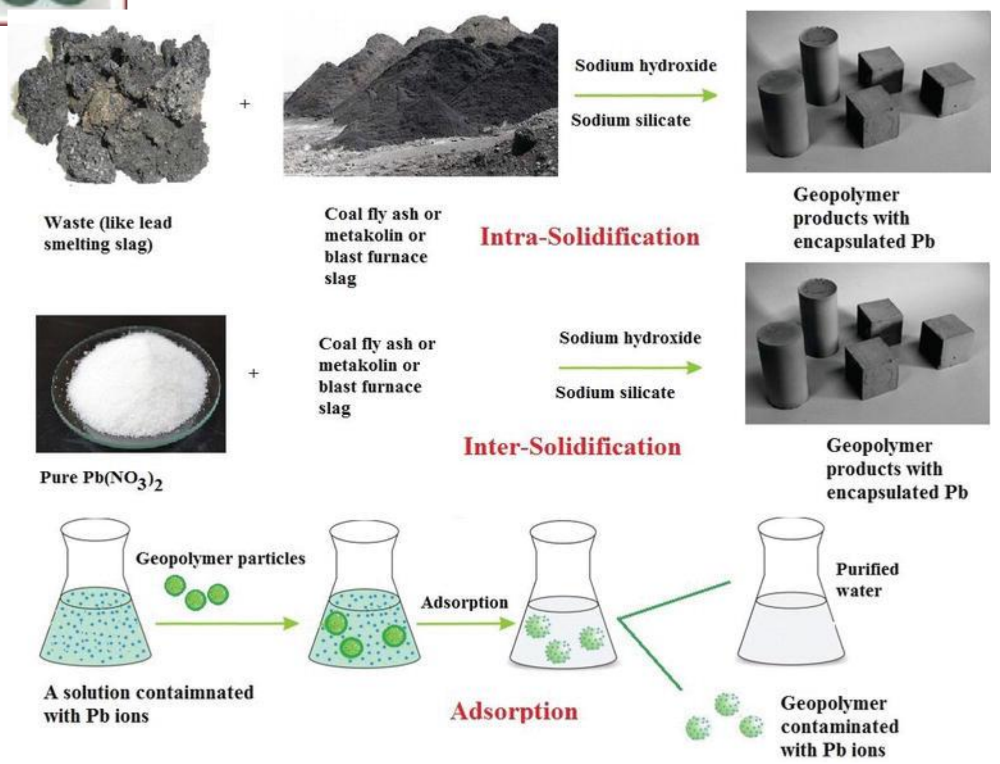
Bricks kept for curing

Ref: Jyothi et al.,

Capping of bricks with plaster-of-Paris.

Immobilisation of toxic wastes in geopolymers





IN CONCLUSION . . . .

- ***Development in the field of concrete technology are far reaching***
- ***Paradigm shifts in concrete concepts are evident***
- ***Geopolymer concrete is emerging as one of the answers for developing 'greener concrete' for sustainable development***


THANK YOU