SACCA WEBINAR
Geopolymer from coal fly ash: production and projects to date

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Environmental Nano Sciences

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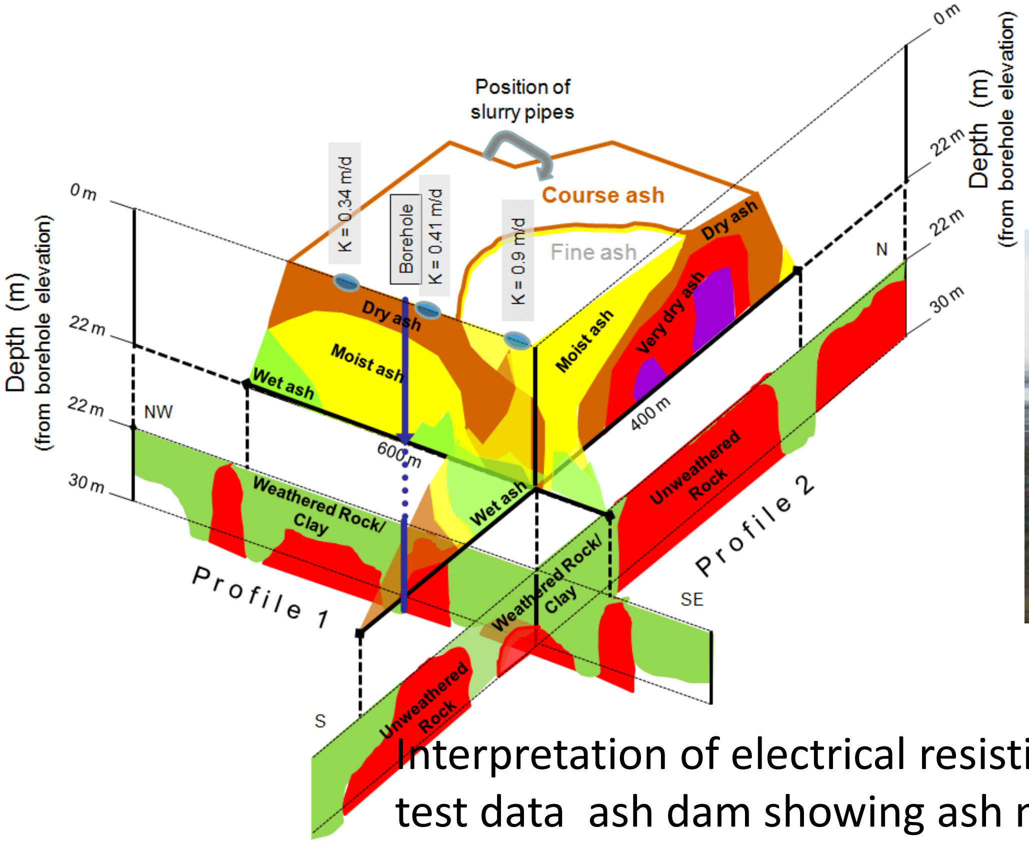
UMKC

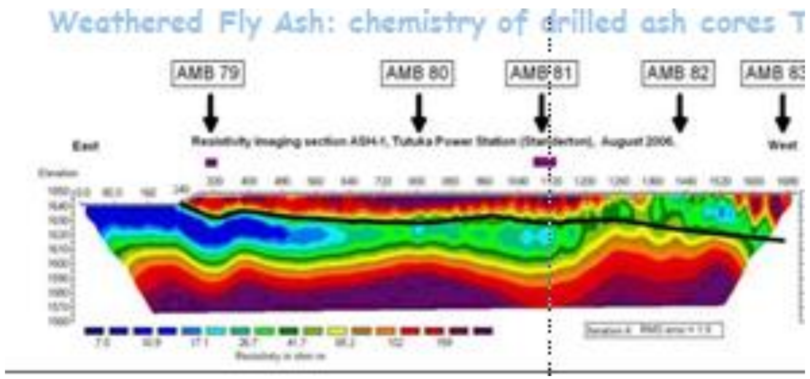
Environmental and Nano Science (ENS group, UWC)

Which ash? Inhomogeneity of ash dumps

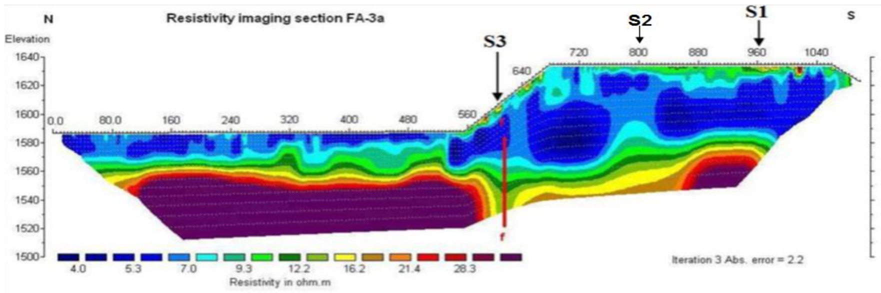
Kragbron



Tutuka



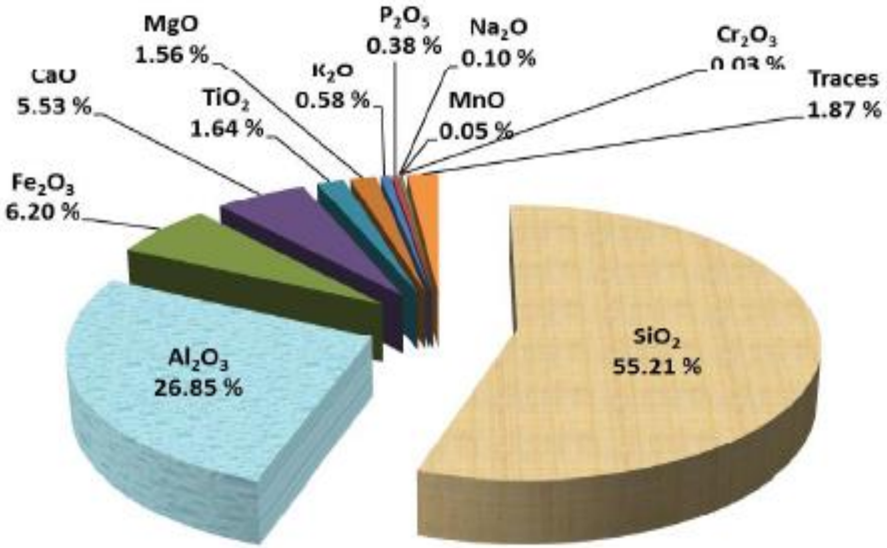
Secunda

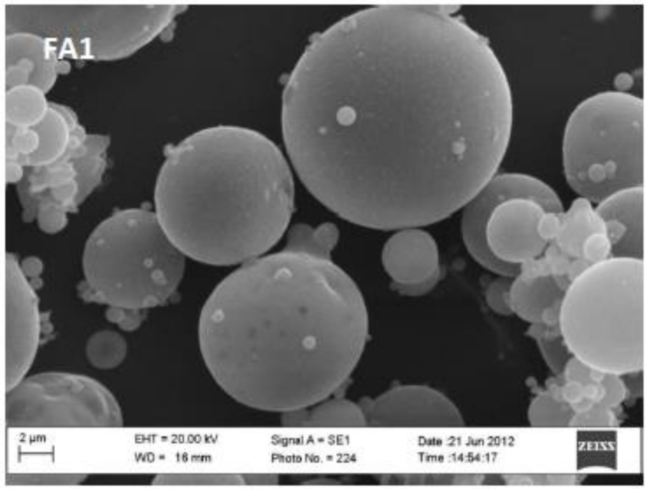


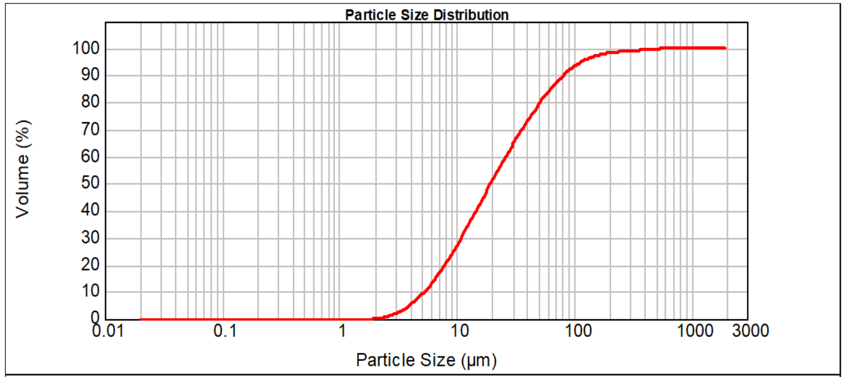
Interpretation of electrical resistivity and hydraulic test data ash dam showing ash moisture content, unsaturated hydraulic conductivity and weathering of the natural geologic environment

Coal fly ash

Particle size	Micron size
Elements	Major: SiO_2, Al_2O_3 and Fe_2O_3 Minor: CaO, MgO and other oxides
Categories	Class F: sum SiO_2 , Al_2O_3 and Fe_2O_3 >70% Class C: sum of SiO_2 , Al_2O_3, Fe_2O_3 is between 50 and 70 %
Environmental effect	Pollution of the air, Contamination of the soil, surface and ground water
Applications	Treatment of mine water, Zeolites synthesis, and Geopolymer synthesis, etc.







Particle size distribution of Lethabo fly ash

Major elements in SA fly ash

	Mean mass %						
Majors	Arnot ash	Matla ash	Tutuka ash	Lethabo ash	Hendrina ash	Kriel ash	Duvha ash
SiO_2	55.21 ± 0.38	58.44 ± 0.40	52.63 ± 0.31	58.32 ± 0.39	55.52 ± 0.38	52.00 ± 0.41	54.92 ± 0.33
Al_2O_3	26.85 ± 0.17	31.25 ± 0.22	26.49 ± 0.19	31.36 ± 0.21	27.30 ± 0.18	31.44 ± 0.20	27.27 ± 0.17
Fe_2O_3	6.20 ± 0.01	3.09 ± 0.03	4.87 ± 0.05	3.04 ± 0.04	3.16 ± 0.02	2.38 ± 0.02	4.78 ± 0.04
CaO	5.53 ± 0.05	3.21 ± 0.04	5.33 ± 0.05	3.16 ± 0.04	3.37 ± 0.02	7.32 ± 0.05	3.69 ± 0.02
TiO_2	1.64 ± 0.07	1.17 ± 0.01	1.46 ± 0.01	1.16 ± 0.01	1.00 ± 0.01	1.25 ± 0.01	0.30 ± 0.00
MgO	1.56 ± 0.03	1.14 ± 0.01	1.31 ± 0.02	1.13 ± 0.01	1.22 ± 0.02	2.03 ± 0.03	1.07 ± 0.01
K_2O	0.58 ± 0.01	0.54 ± 0.01	0.82 ± 0.01	0.54 ± 0.01	0.51 ± 0.01	0.57 ± 0.01	0.66 ± 0.01
P_2O_5	0.38 ± 0.00	0.40 ± 0.02	0.38 ± 0.01	0.39 ± 0.02	0.35 ± 0.01	0.47 ± 0.03	0.61 ± 0.04
Na_2O	0.10 ± 0.08	0.46 ± 0.02	0.55 ± 0.04	0.46 ± 0.03	0.25 ± 0.02	0.65 ± 0.04	0.07 ± 0.00
MnO	0.05 ± 0.00	0.02 ± 0.00	0.05 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.05 ± 0.00
LOI	6.27 ± 0.00	0.28 ± 0.02	6.09 ± 0.06	0.40 ± 0.02	7.45 ± 0.08	1.83 ± 0.02	4.44 ± 0.04
Sum	104.37	100.00	99.98	99.98	100.16	99.97	97.86
SiO_2/Al_2O_3	2.06	1.87	1.99	1.86	2.03	1.65	2.01

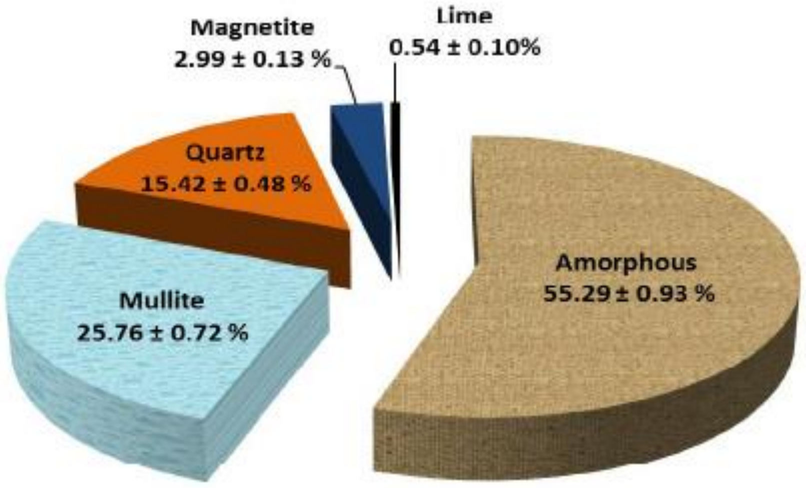
Trace elements

The trace elements together account for approximately 1.87 % by mass of the total ash content

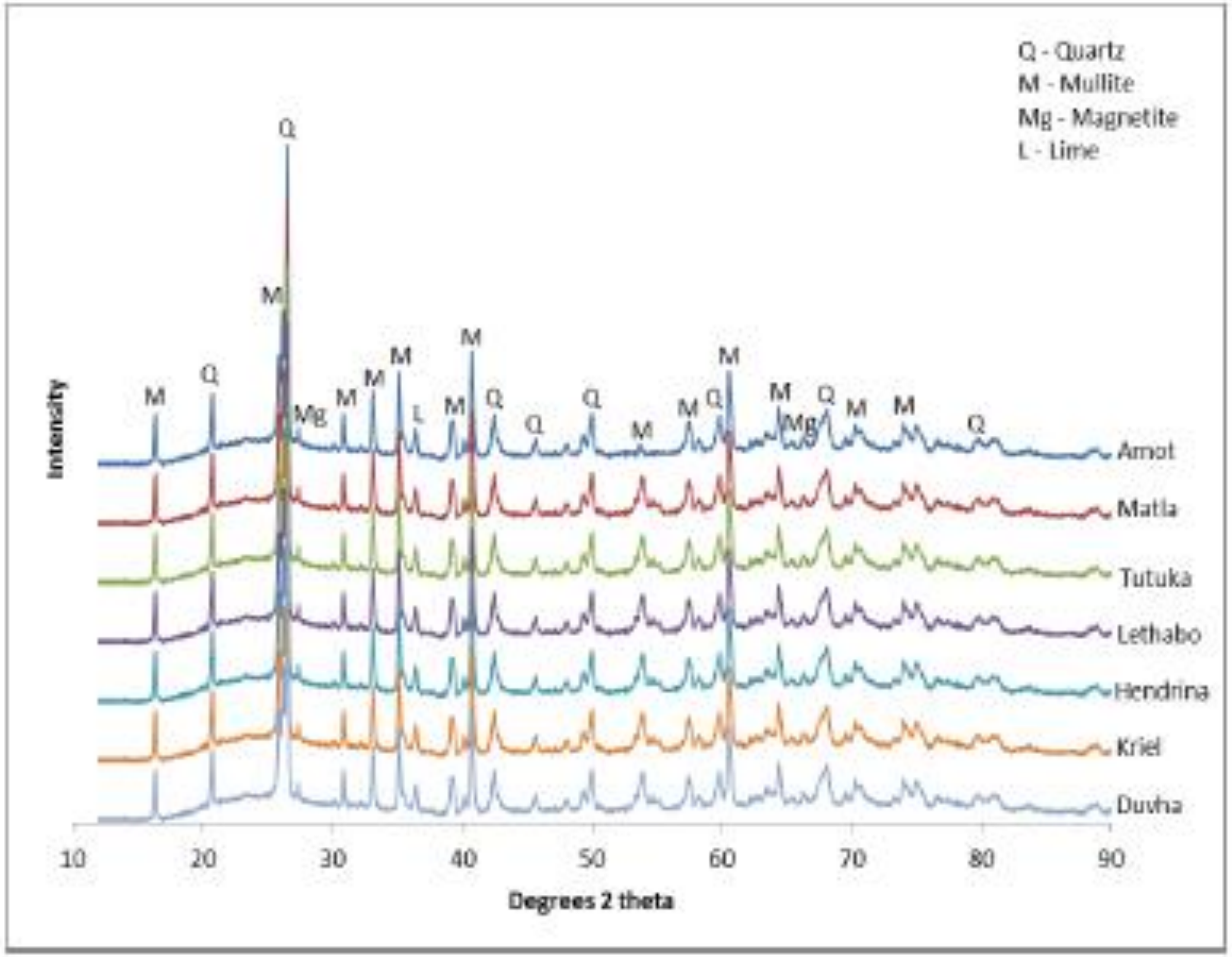
NOTE the radionuclides

	mg/kg						
Traces	Arnot ash	Matla ash	Tutuka ash	Lethabo ash	Hendrina ash	Kriel ash	Duvha ash
Ba	898.33 ± 2.31	917.53 ± 3.01	913.11 ± 2.98	918.23 ± 2.99	1154.52 ± 3.13	1271.20 ± 3.22	952.12 ± 2.98
Sr	835.00 ± 0.00	976.19 ± 2.65	1384.72 ± 9.66	970.66 ± 4.01	1167.71 ± 8.33	2135.95 ± 11.22	957.41 ± 5.10
Zr	408.00 ± 0.00	384.58 ± 2.33	492.99 ± 3.00	385.24 ± 6.67	445.03 ± 8.22	434.70 ± 3.12	527.84 ± 5.66
Ce	212.33 ± 12.50	107.75 ± 5.23	155.80 ± 4.01	112.73 ± 3.00	166.86 ± 3.01	124.90 ± 3.00	135.93 ± 2.88
V	149.00 ± 3.00	110.70 ± 3.01	122.29 ± 5.33	123.49 ± 4.56	105.68 ± 3.15	88.73 ± 2.01	125.55 ± 5.82
Y	73.67 ± 0.58	71.71 ± 1.22	98.29 ± 2.00	73.72 ± 0.79	92.87 ± 0.94	88.73 ± 1.47	76.71 ± 2.77
Ni	71.00 ± 4.36	20.45 ± 0.86	22.04 ± 0.90	21.95 ± 1.01	24.90 ± 1.00	20.41 ± 0.88	72.29 ± 3.63
Zn	67.33 ± 1.15	39.48 ± 0.66	38.03 ± 0.58	39.54 ± 0.65	61.69 ± 2.01	23.44 ± 0.22	118.28 ± 3.55
Pb	49.33 ± 0.58	51.81 ± 1.23	48.83 ± 0.98	51.71 ± 2.00	49.66 ± 1.81	23.48 ± 0.21	82.61 ± 4.66
Cu	37.67 ± 8.39	55.71 ± 2.01	51.43 ± 2.22	53.85 ± 3.31	47.32 ± 3.12	45.59 ± 2.44	50.88 ± 3.00
Th	36.00 ± 1.00	373.09 ± 8.66	558.96 ± 14.12	372.75 ± 6.42	448.59 ± 8.00	920.80 ± 10.22	765.34 ± 9.25
Rb	35.67 ± 0.58	35.77 ± 0.64	41.01 ± 0.48	27.57 ± 0.22	41.08 ± 0.65	27.95 ± 0.20	42.14 ± 3.04
Nb	31.67 ± 0.58	57.66 ± 2.55	65.92 ± 8.01	53.05 ± 3.44	41.21 ± 3.78	72.21 ± 6.24	38.54 ± 1.22
As	18.67 ± 0.58	41.09 ± 1.88	85.70 ± 7.00	41.09 ± 2.55	50.99 ± 3.21	43.38 ± 2.66	34.78 ± 3.33
U	6.67 ± 2.31	38.69 ± 1.77	10.12 ± 0.26	58.48 ± 3.88	59.73 ± 6.00	41.82 ± 3.65	29.10 ± 2.01
Co	3.33 ± 0.58	17.97 ± 0.51	39.52 ± 2.01	14.84 ± 0.20	32.84 ± 3.66	17.40 ± 0.25	33.32 ± 2.77

Mineralogy of fly ash

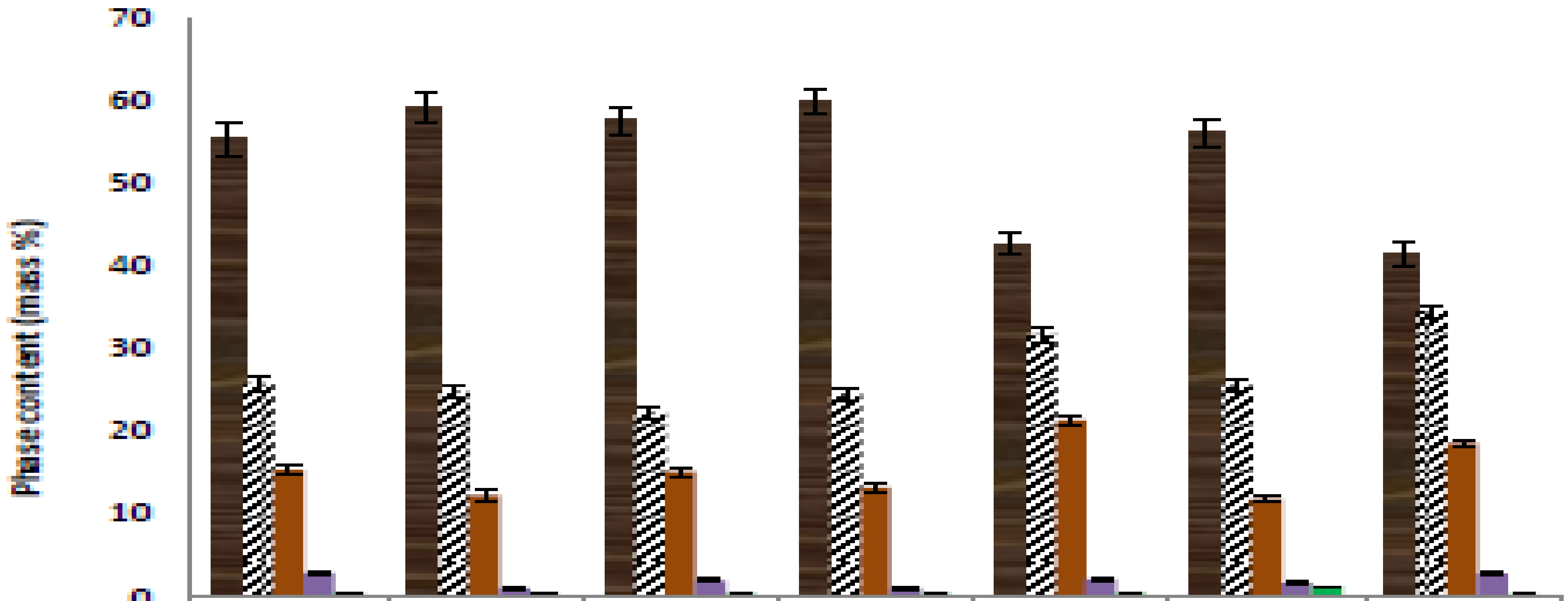


Mineral phase quantification



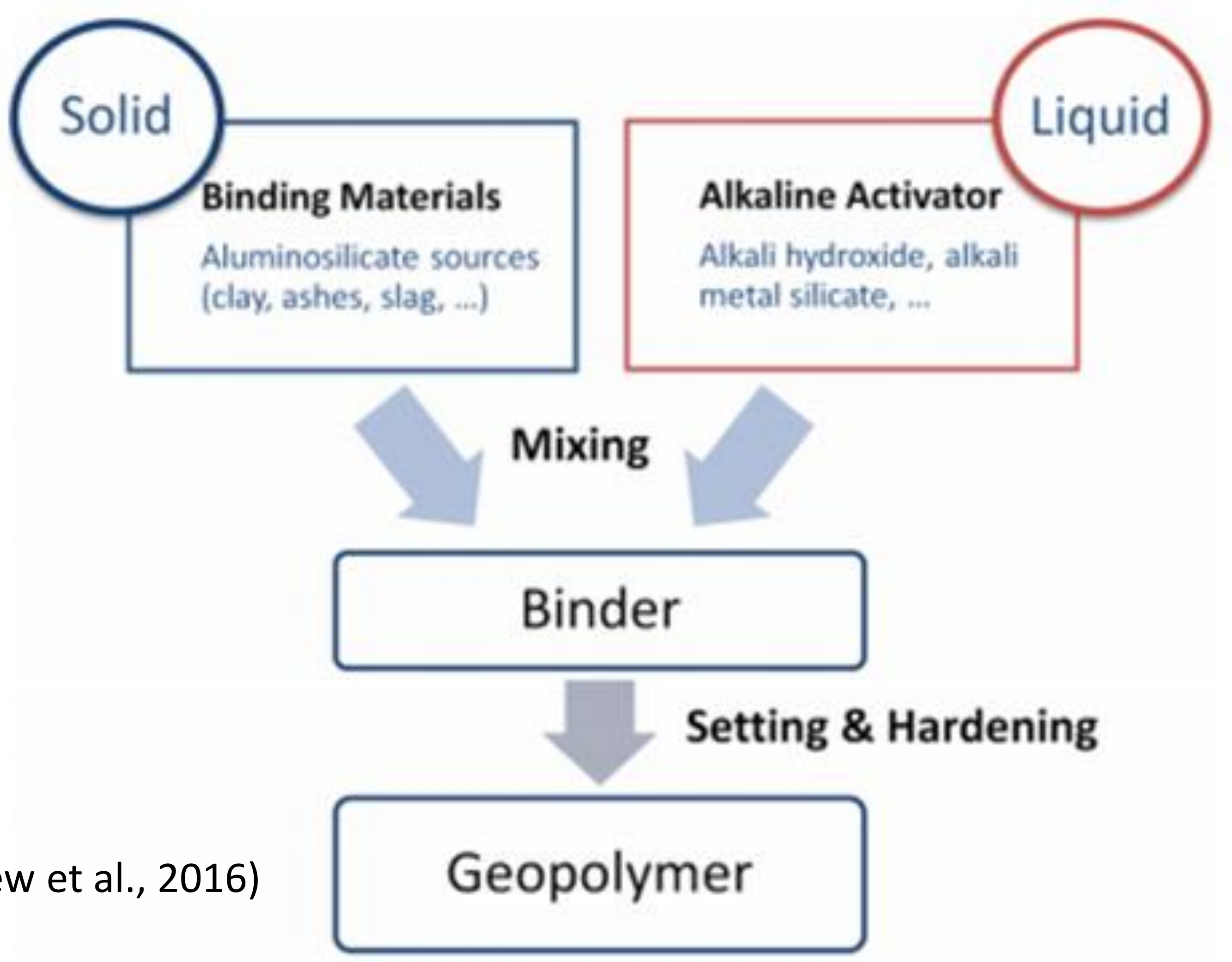
Qualitative XRD spectrum of fresh fly ash

Amorphous glassy phase

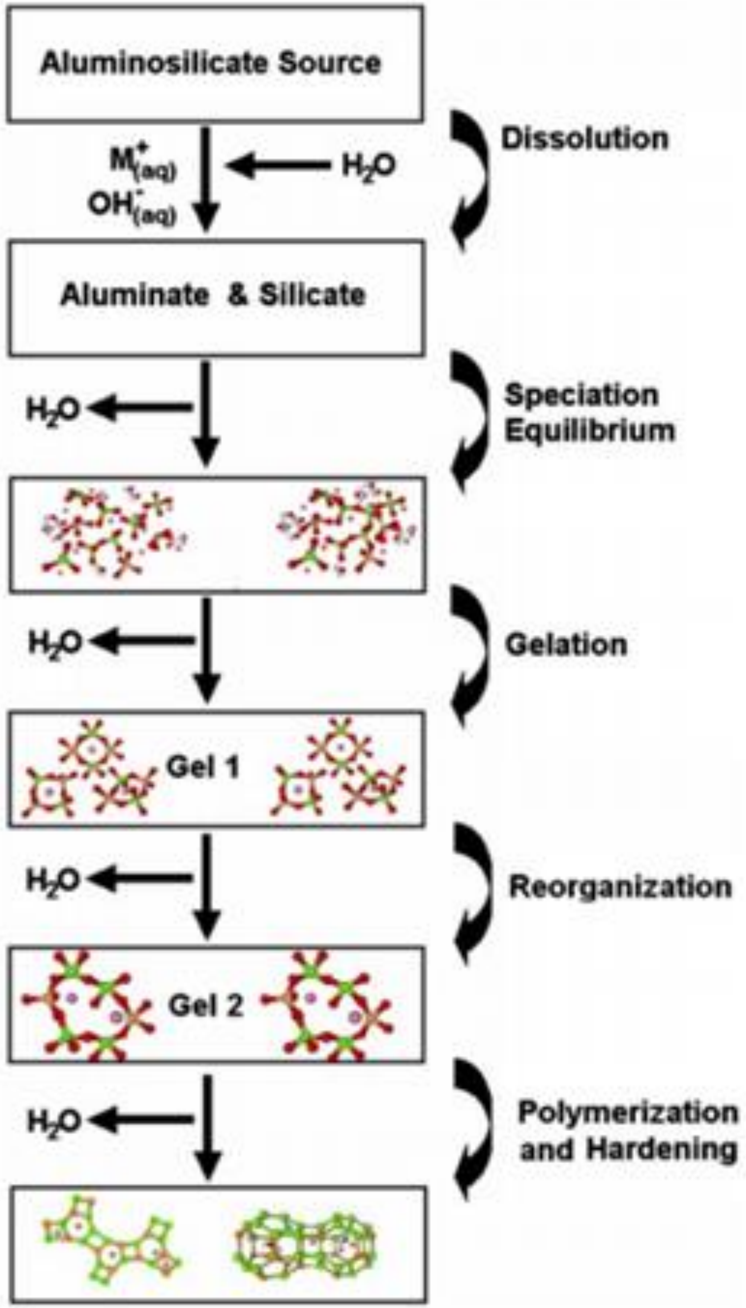


	Arnot	Matla	Tutuka	Lethabo	Hendrina	Kriel	Duvha
Amorphous	55.29	59.06	57.54	59.79	42.60	56.00	41.55
Mullite	25.76	24.84	22.27	24.49	31.72	25.54	34.55
Quartz	15.42	12.33	15.20	13.27	21.38	11.92	18.61
Magnetite	2.99	1.13	2.04	1.14	2.24	1.78	2.90
Lime	0.54	0.42	0.50	0.47	0.46	1.39	0.40

Geopolymer processing



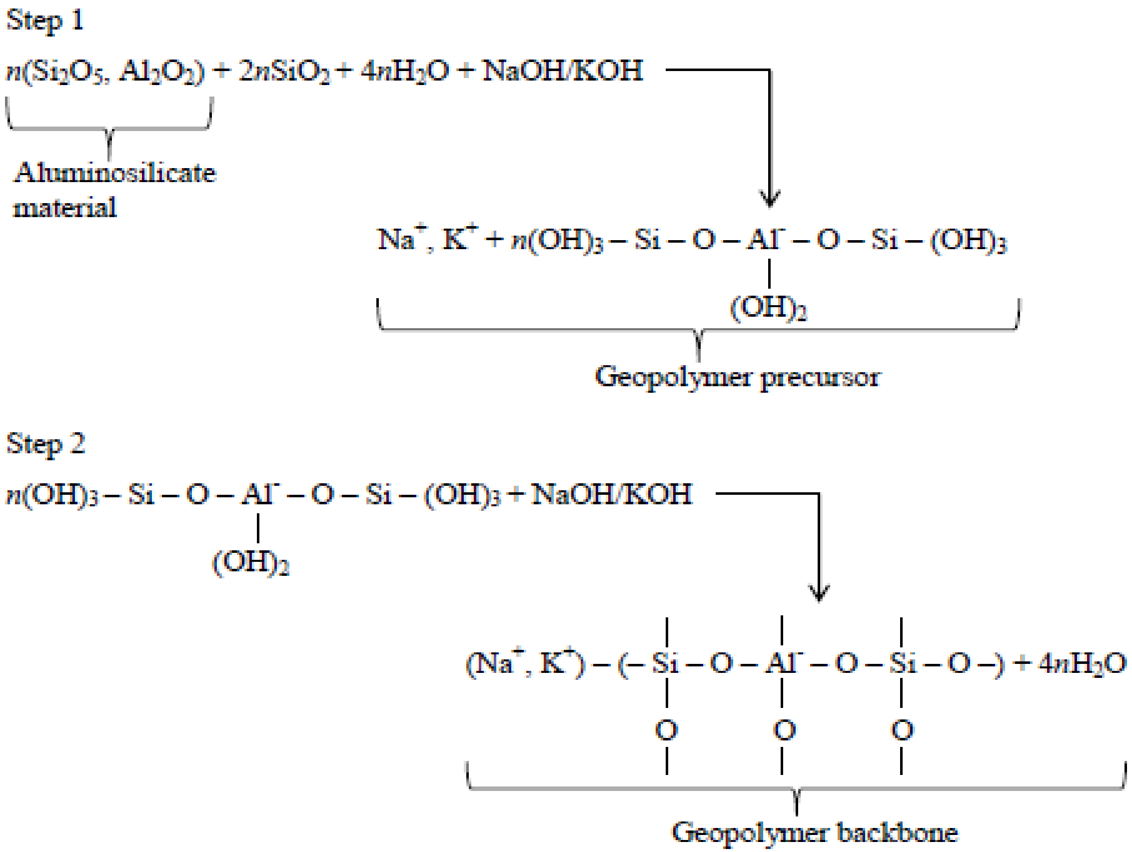
(Liew et al., 2016)



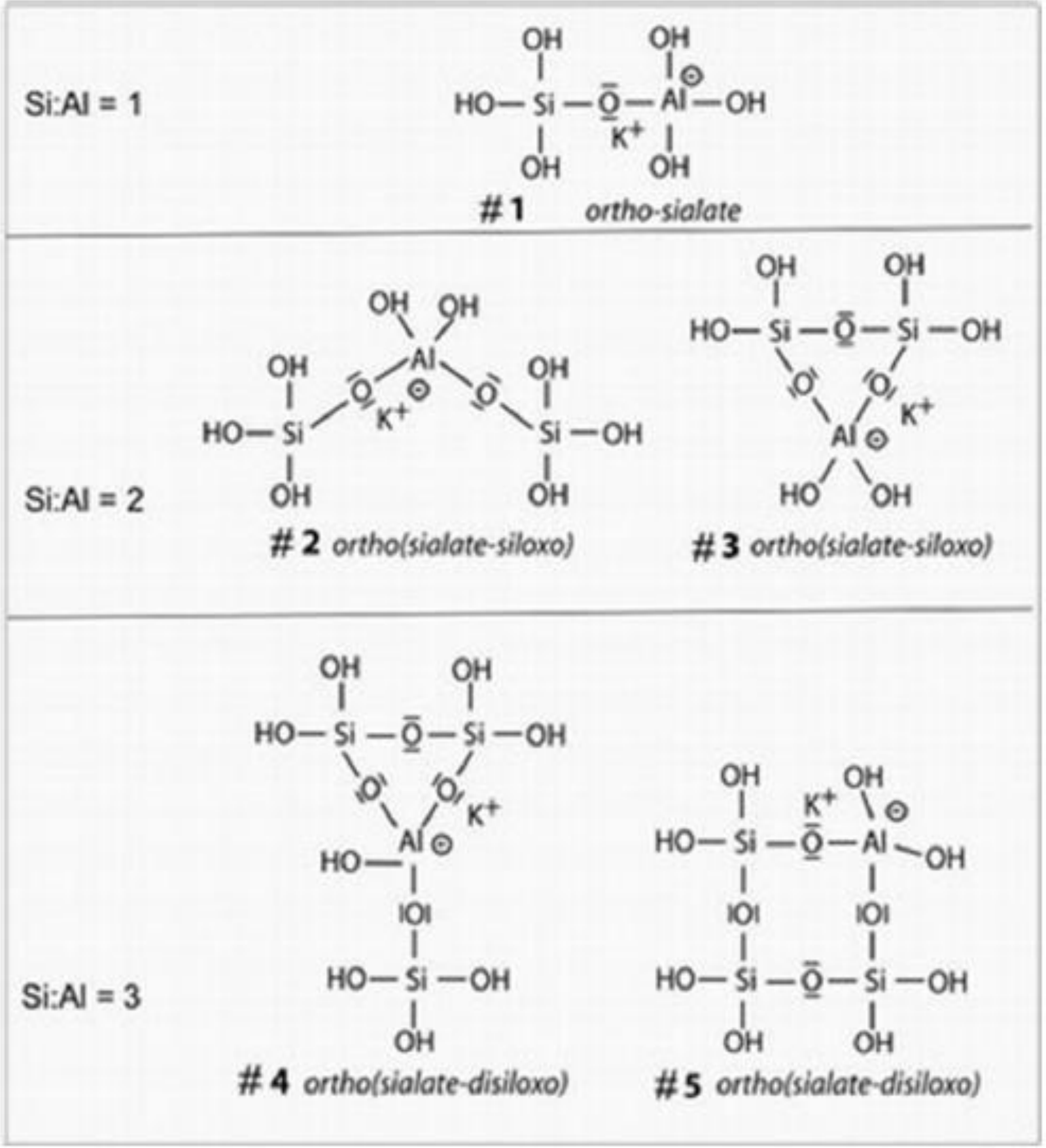
Process of geopolymersation (Duxson et al., 2007)

Geopolymer chemistry

inorganic polycondensation reaction



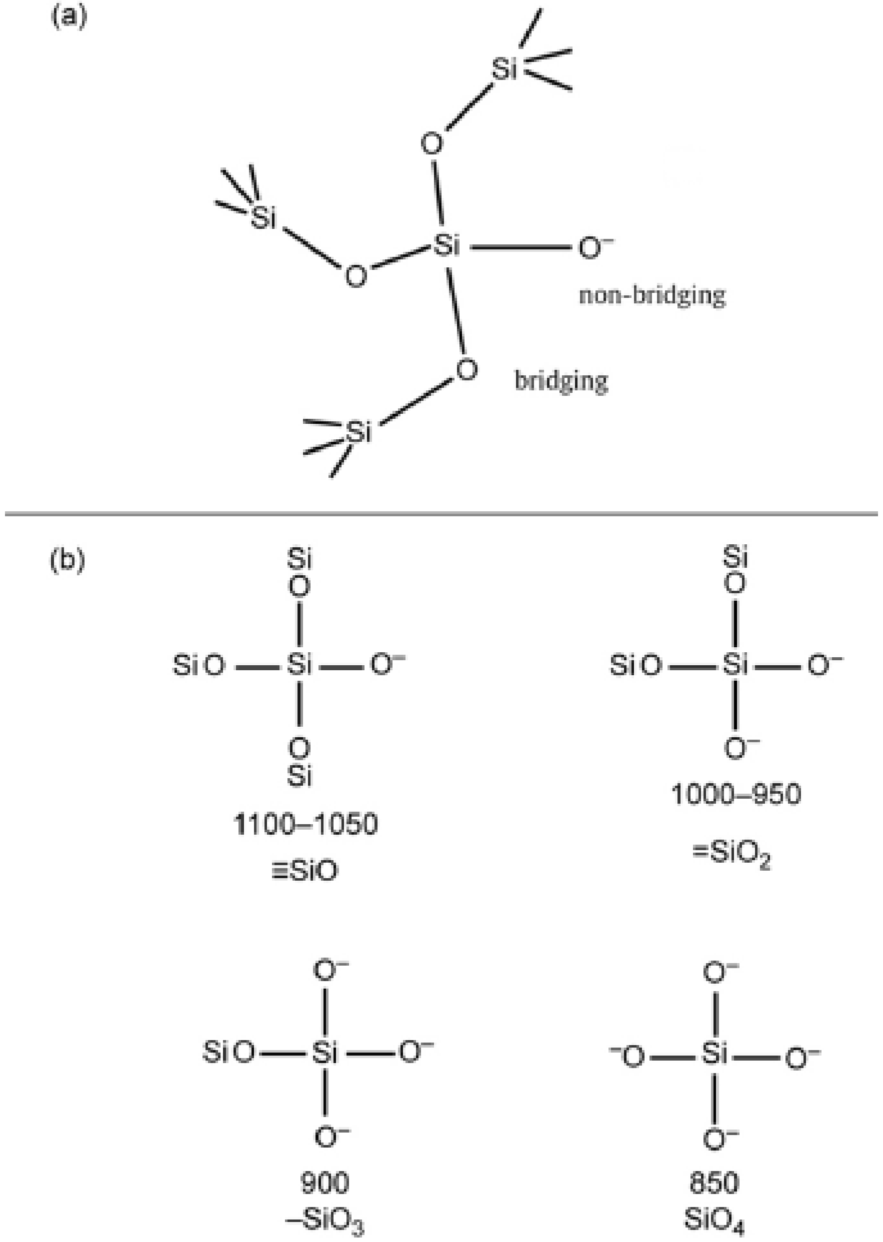
Swanepoel & Strydom, 2002



The framework structure of geopolymers based on different Si/Al ratios (Source: Davidovits, 2008)

Silicate structural units

Silicate structural units (a) bridging and non-bridging oxygen in Si tetrahedron (b) tetrahedral silica units with one, two, three and four non-bridging oxygens (Source: McMillan, 1984).



Strength requirements for masonry units and mortar

The compressive strength of concrete and clay masonry units internationally used for building and construction purposes range between 1000 psi (6.9 MPa) and 14400 psi (99.3 MPa) (Portland Cement Association, 1993).

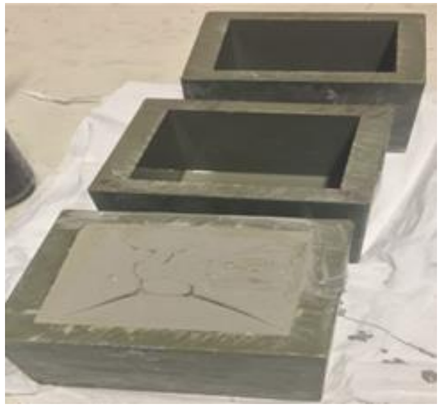
Wall type	Position	Minimum average compressive strength (MPa)		Class of mortar required
		Solid units	Hollow units	
Structural other than foundation and retaining walls	Single storey building - internal or external	7.0	3.5	II
	Double storey building - internal or external	10.5 or 14.0	7.0	II
Non-structural other than parapet, balustrade and free-standing walls	External	7.0	3.5	II
	Internal	7.0	3.5	III
Free-standing	External or internal	10.5	7.0	II
Foundation	Supporting single storey	7.0	3.5	II
Foundation	Supporting double storey	10.5 or 14.0	7.0	II
Parapet	-	7.0	3.5	II
Balustrade	-	7.0	3.5	II
Retaining	-	10.5	7.0	II

Source: (Clay Brick Association of South Africa, 2012).

Study 1.1:
Lightweight, low density foamed geopolymer from South African fly ash

Variables investigated and optimized were:

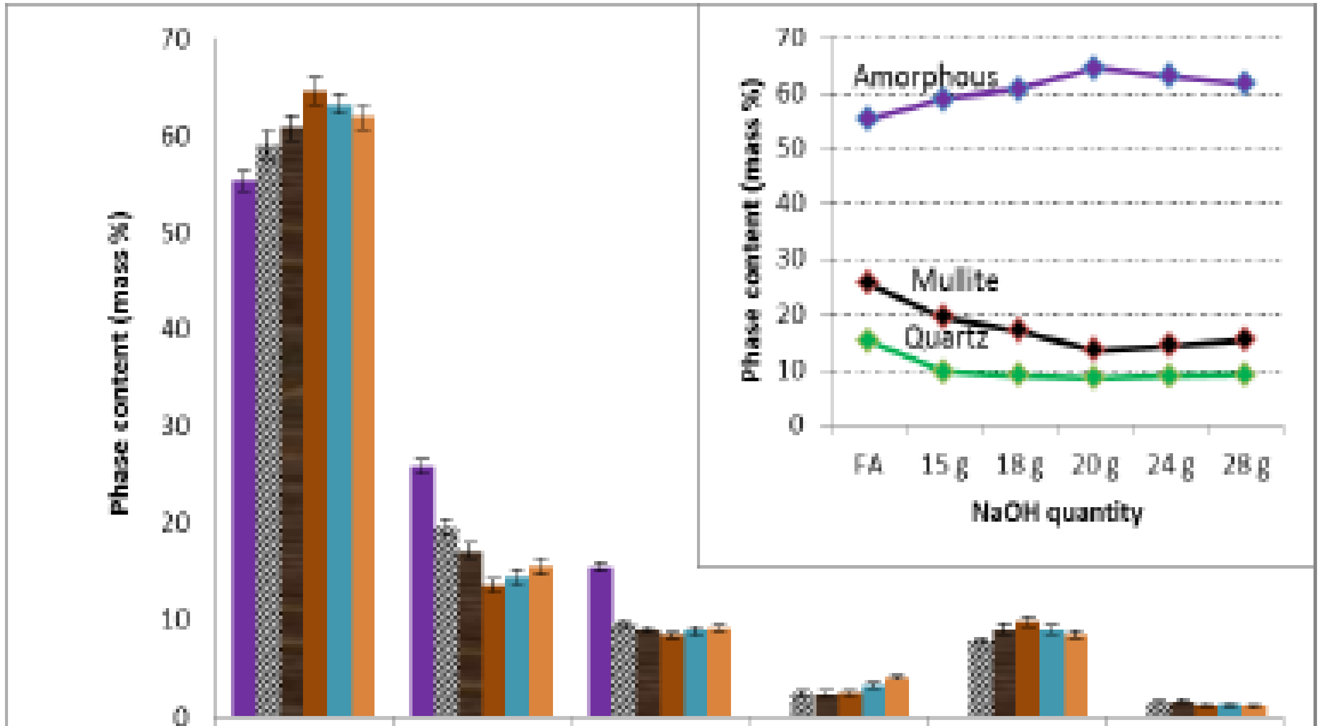
- amount of NaOH
- type and amount of foaming agent
- amount of water
- room temperature curing time
- hydrothermal curing temperature and time



Dr S.Nyale

Foamed Geopolymer mineralogy

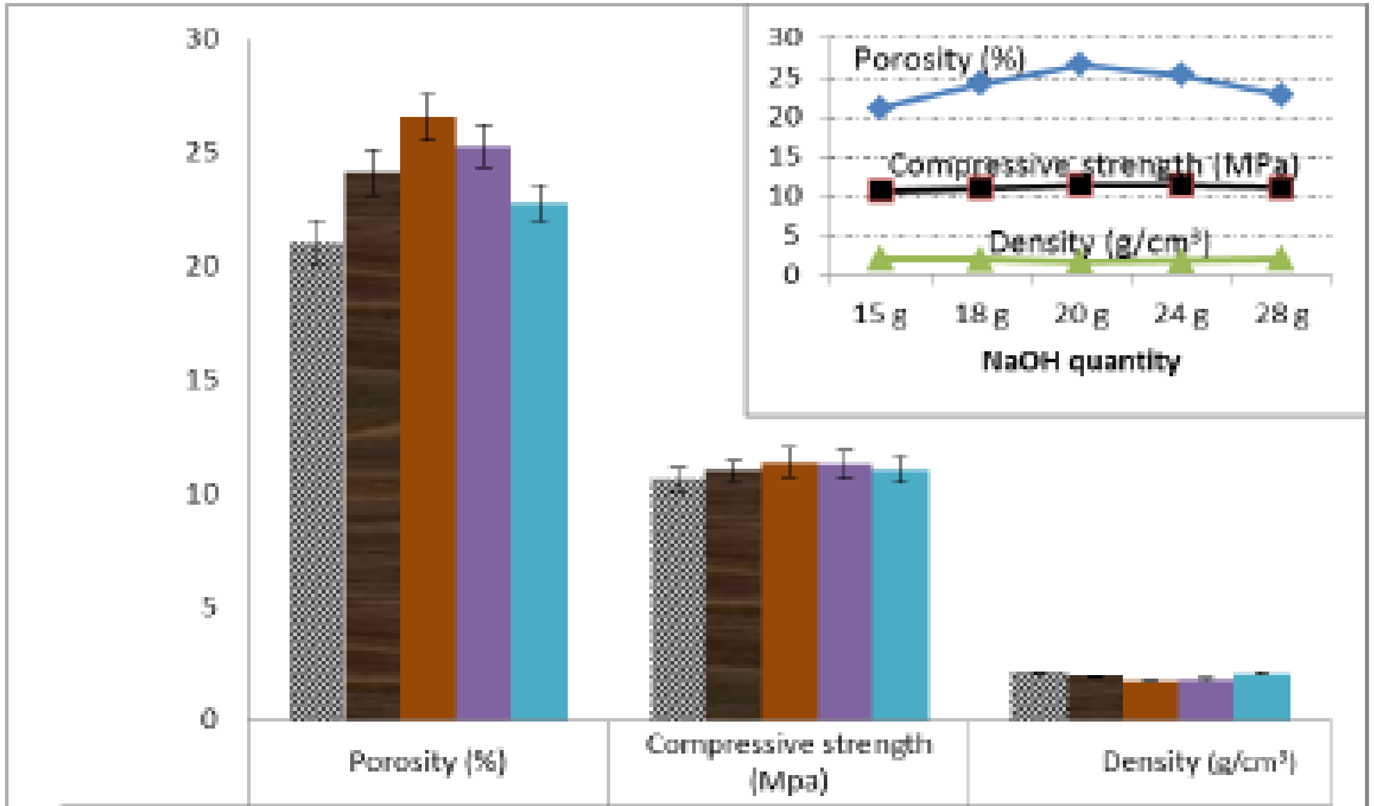
XRD mineral phase quantification of Arnot fly ash (FA) and foamed geopolymers synthesized using different quantities of NaOH (15 g, 18 g, 20 g, 24 g and 28 g); parameters held constant: fly ash (100 g), foaming agent (38 g), water (33 g), room temperature curing (2 hours), hydrothermal treatment at 80 °C for 5 days (n=3) (nd=not detected).



	Amorphous	Mullite	Quartz	Halite	Sodalite	Tobermorite
FA	55.29	25.76	15.42	nd	nd	nd
15 g NaOH	58.99	19.55	9.75	2.41	7.86	1.44
18 g NaOH	60.78	17.13	9.02	2.42	9.04	1.61
20 g NaOH	64.55	13.55	8.43	2.43	9.87	1.17
24 g NaOH	63.16	14.39	8.92	3.31	9.00	1.22
28 g NaOH	61.82	15.50	9.11	4.04	8.46	1.07

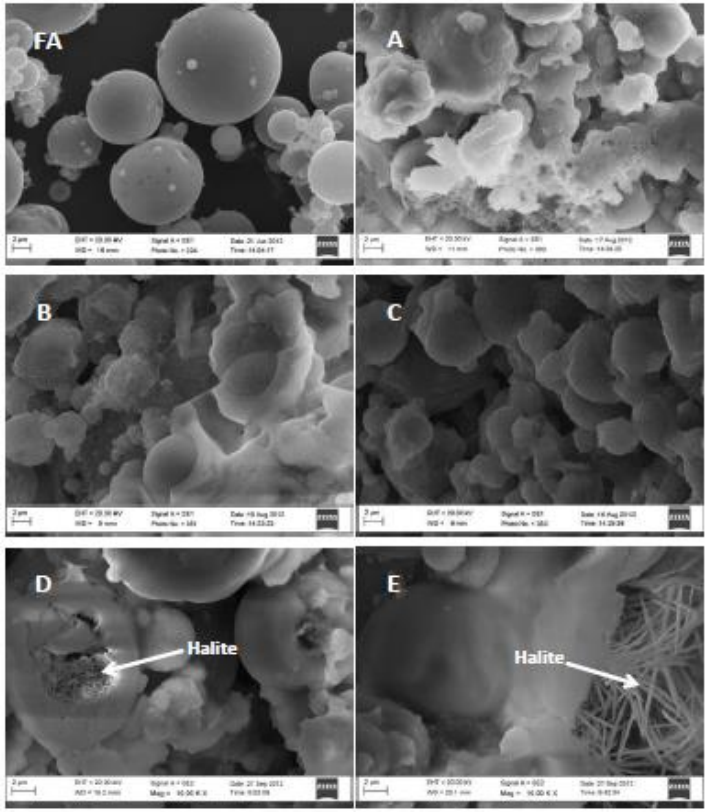
Porosity, density and compressive strength

Foamed geopolymers synthesized using different quantities of NaOH (15 g, 18 g, 20 g, 24 g and 28 g);
Constant parameters: fly ash (100 g), foaming agent (38 g), water (33 g), room temperature curing (2 hours), hydrothermal treatment at 80 °C for 5 days (n=3).

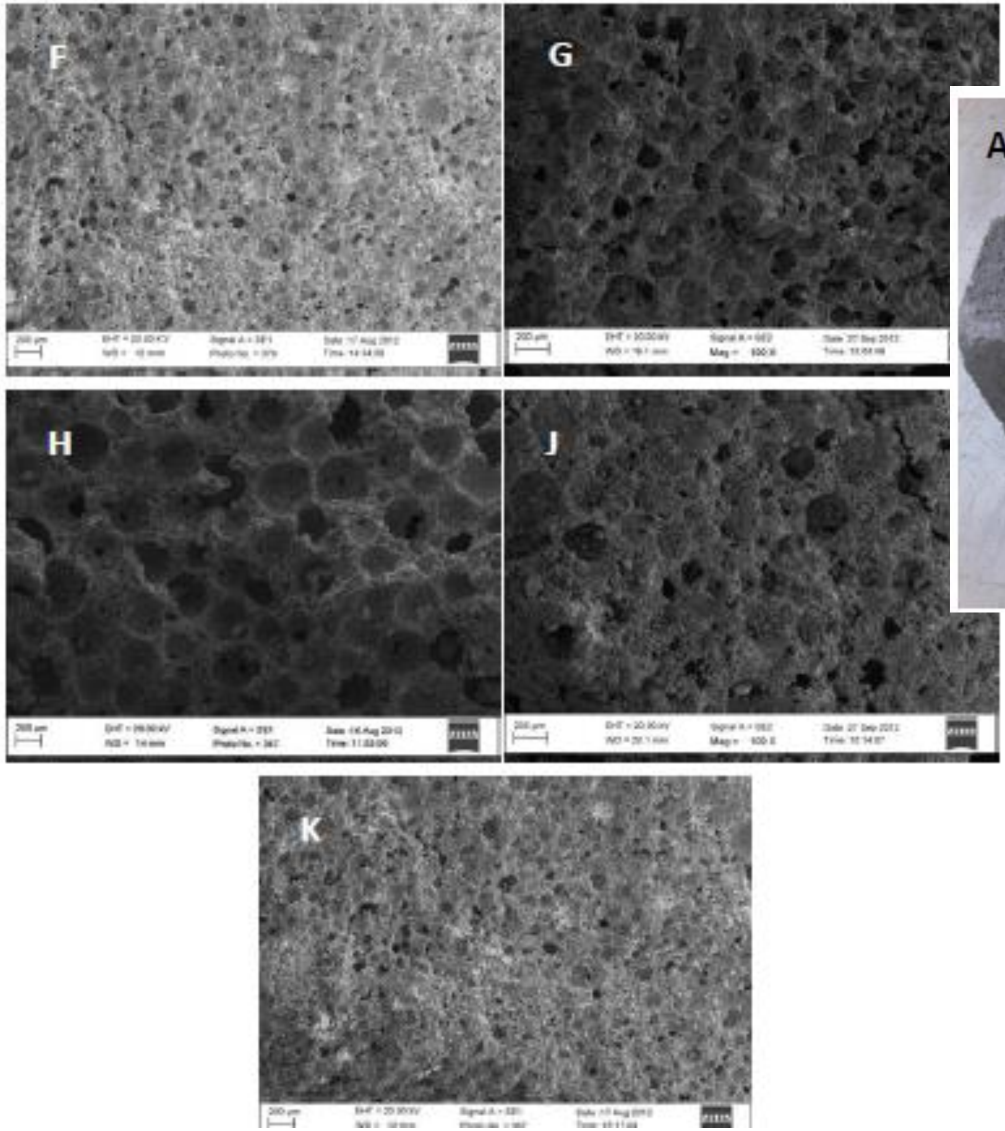


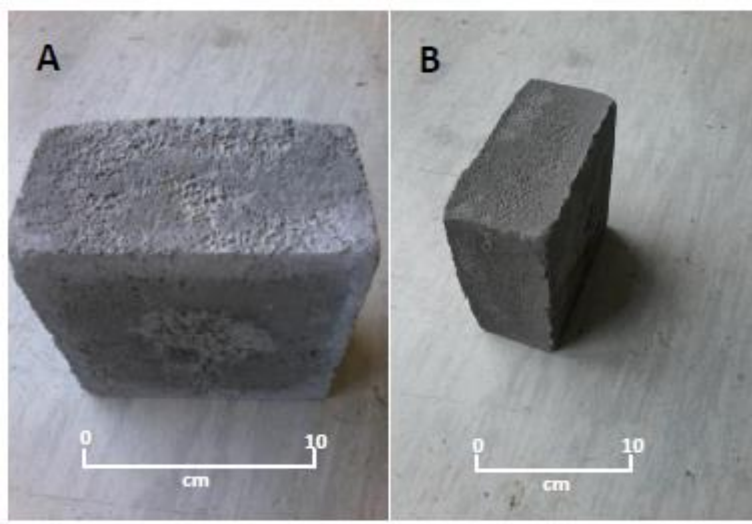
	Porosity (%)	Compressive strength (Mpa)	Density (g/cm³)
15 g NaOH	21.03	10.63	2.09
18 g NaOH	24.11	10.99	1.93
20 g NaOH	26.56	11.38	1.72
24 g NaOH	25.29	11.30	1.80
28 g NaOH	22.78	11.05	2.08

Morphology of foamed geopolymers



SEM images of Arnot fly ash (FA) and
foamed geopolymers



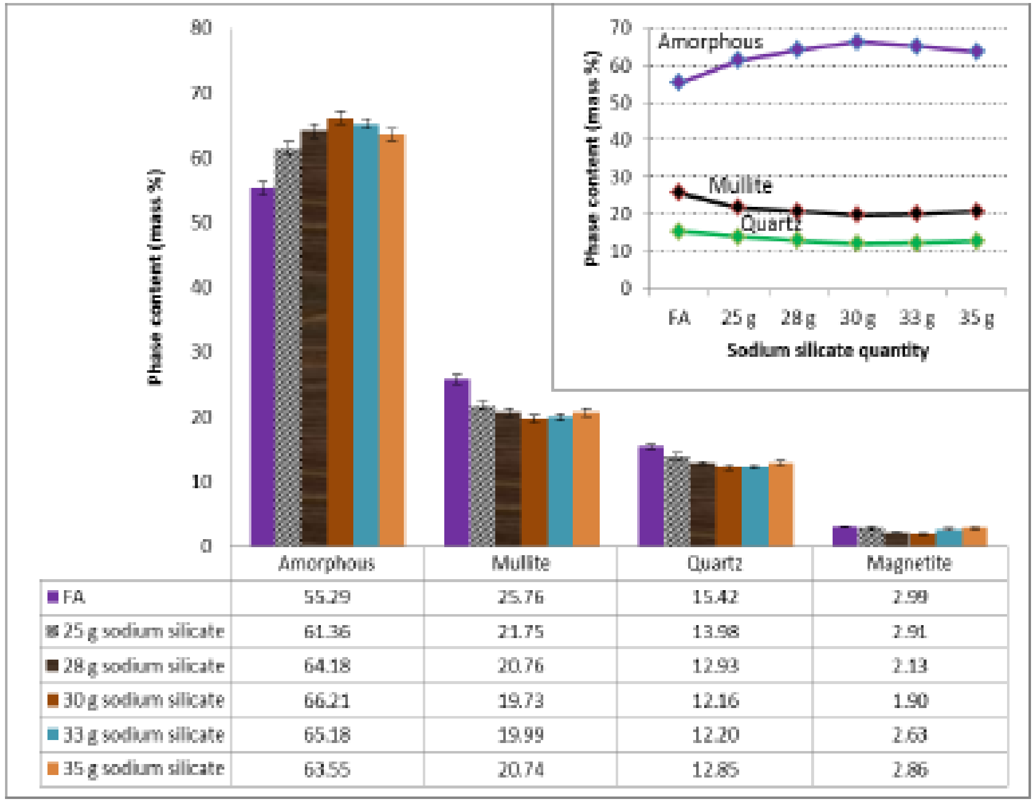


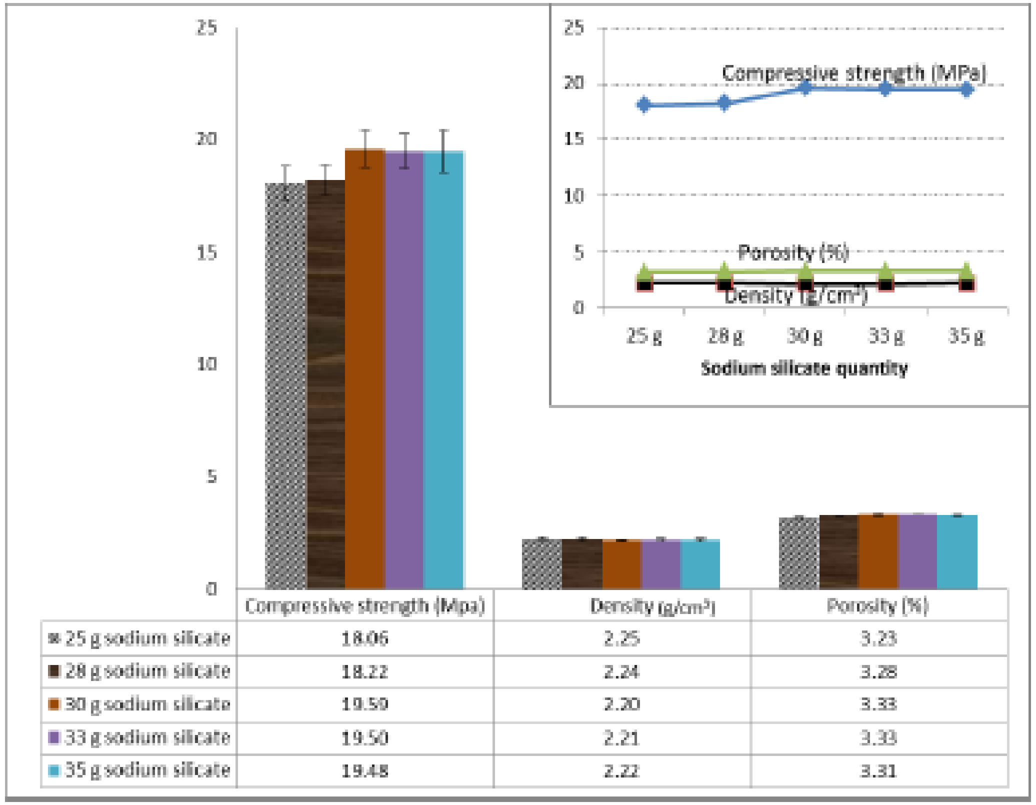
Foamed geopolymer:
26.56 % porosity,
11.38 MPa compressive strength
1.72 g/cm3 density

Study 1.2:
Sodium silicate based geopolymer
Room Temperature curing

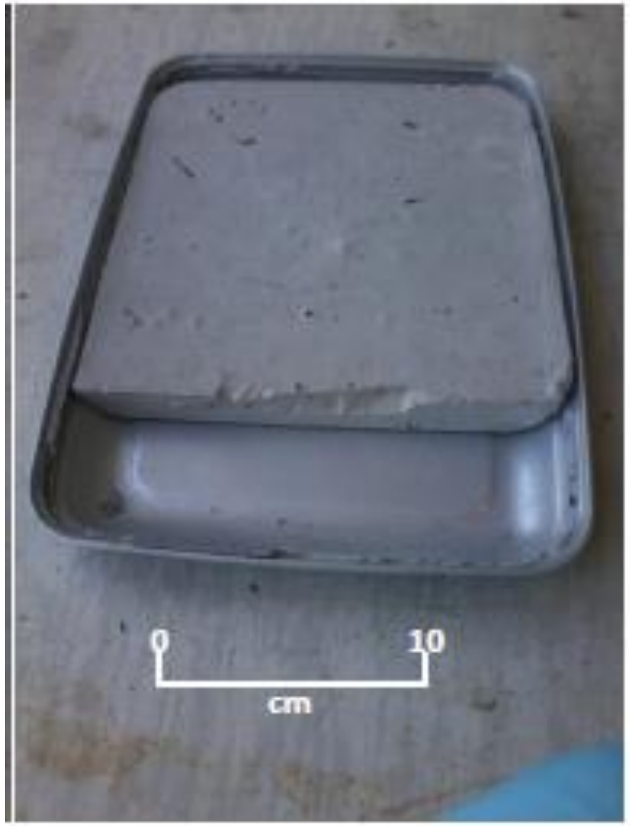
- Fly ash: Na_2SiO_3: H_2O mass ratio of 3.33: 1.00: 1.00
- set at room temperature ≈25 °C undisturbed and without any other form of external heating for 30 days.
- fly ash-sodium silicate based geopolymer had compressive strength of 19.59 MPa, density of 2.20 g/cm^3 and 3.33 % porosity.

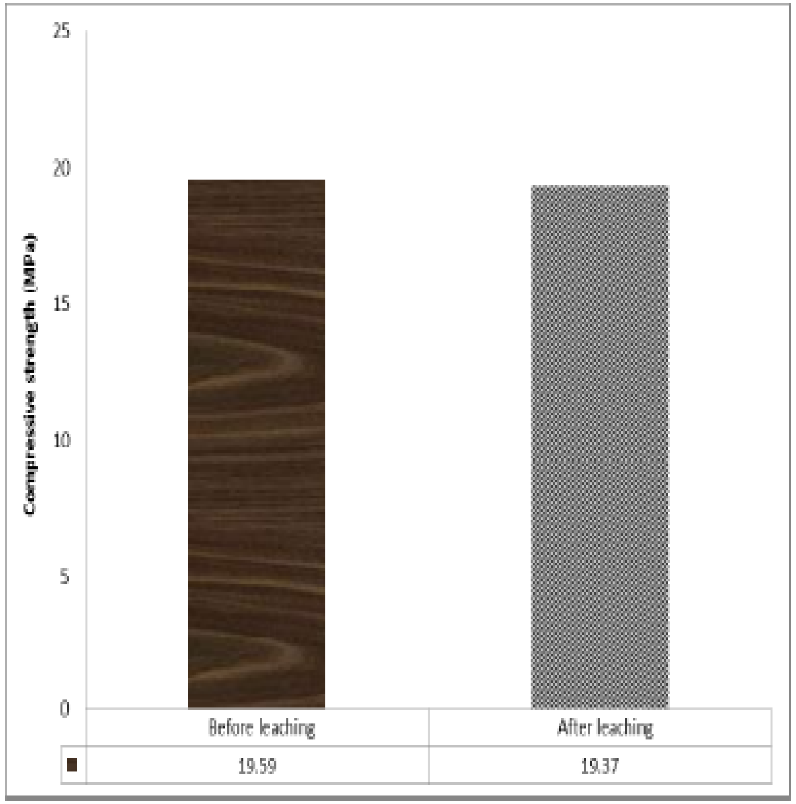
Sodium silicate based geopolymer





Product quality





Comparison of compressive strength of SG geopolymer

Fly ash: Na2SiO3: H2O mass ratio of 3.33: 1.00: 1.00;

cured at room temp ≈25 °C for 30 days)

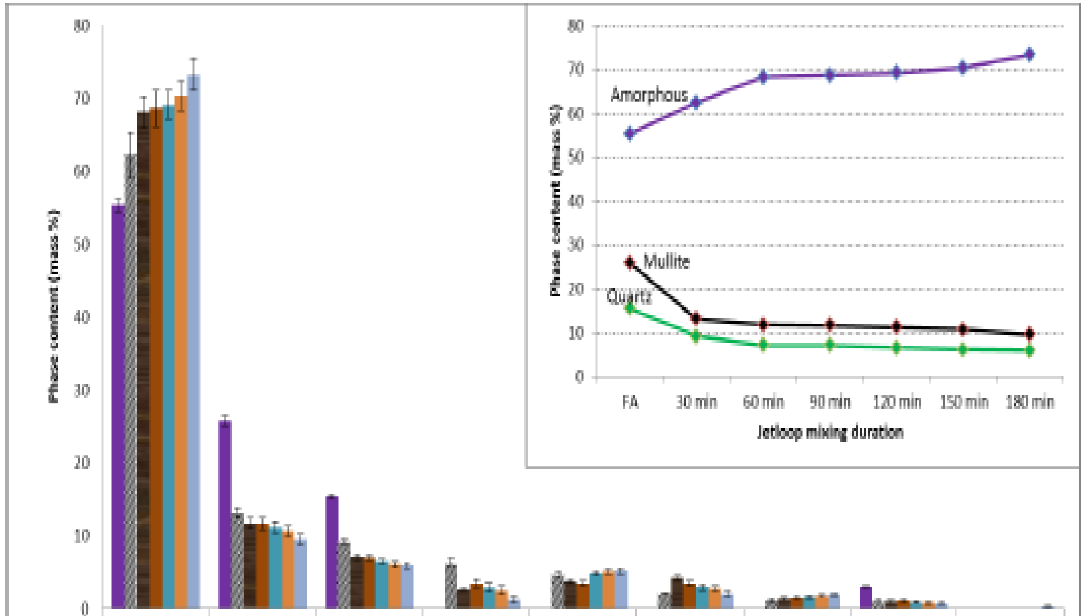
Compressive strength:
prior to leaching 19.59 MPa
after leaching was 19.37 MPa

Study 1.3: Novel mixing technique

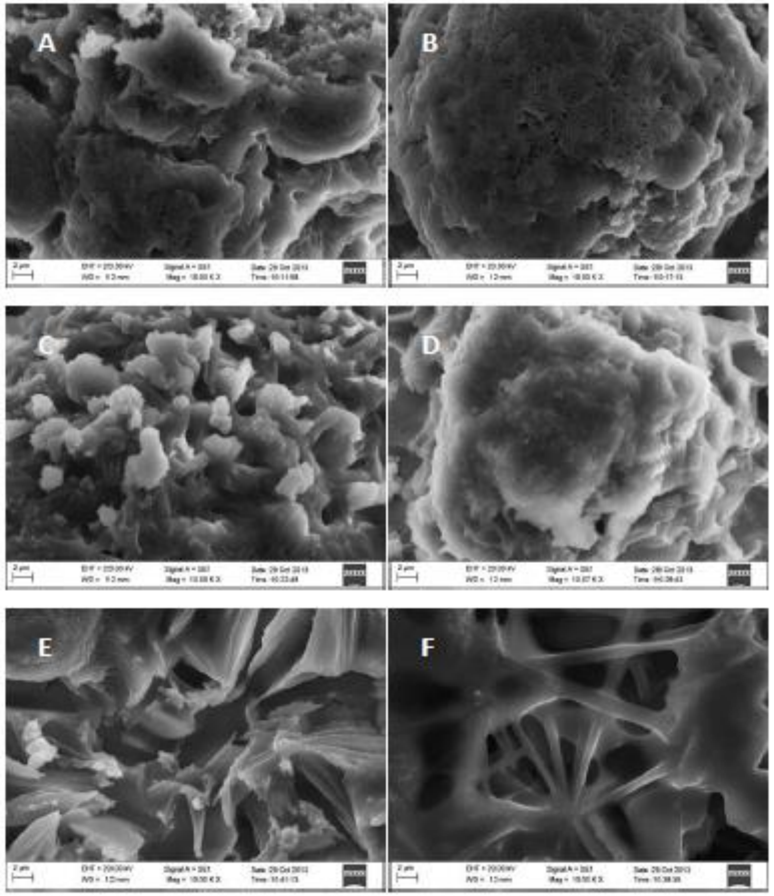
Fly ash-based geopolymer formed using the jetloop reactor

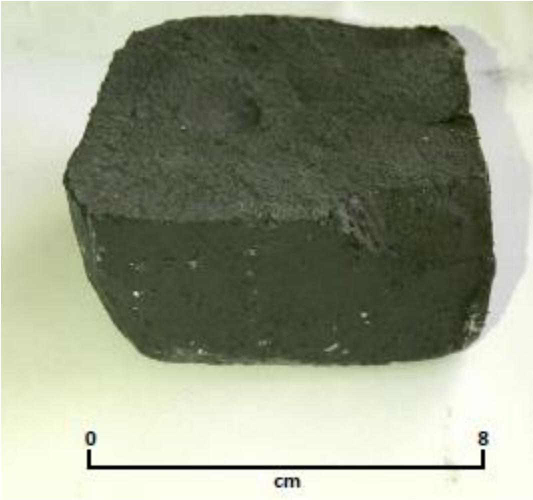
- fly ash: NaOH: H2O mass ratio of 1.00: 1.00: 5.00
- 180 min of continuous jetloop mixing
- hydrolysis of most crystalline mineral phases present in the original raw fly ash converted into an amorphous aluminosilicate gel like matrix
- subsequent hydrothermal treatment of the resulting mixture at 80 °C for 5 days
- sample had a soft gelatinous matrix
- potential as a grouting agent or sealant due to its plasticity and long term stability in the gel form

Mineralogy and morphology after jetloop mixing



	Amorphous	Mullite	Quartz	Natrite	Sodalite	Sodium silicate hydrate	Thermonatrite	Magnetite	Zeolite NaHY10
FA	55.29	25.76	15.42	nd	nd	nd	nd	2.99	nd
30 min	62.34	13.15	9.15	6.27	4.69	2.11	1.20	1.09	nd
60 min	68.14	11.67	7.13	2.70	3.76	4.21	1.35	1.04	nd
90 min	68.61	11.62	7.05	3.47	3.40	3.38	1.44	1.03	nd
120 min	69.10	11.15	6.54	2.91	4.86	2.96	1.59	0.80	nd
150 min	70.31	10.69	6.09	2.49	5.11	2.74	1.77	0.80	nd
180 min	73.18	9.50	5.95	1.23	5.16	2.01	1.95	0.71	0.31

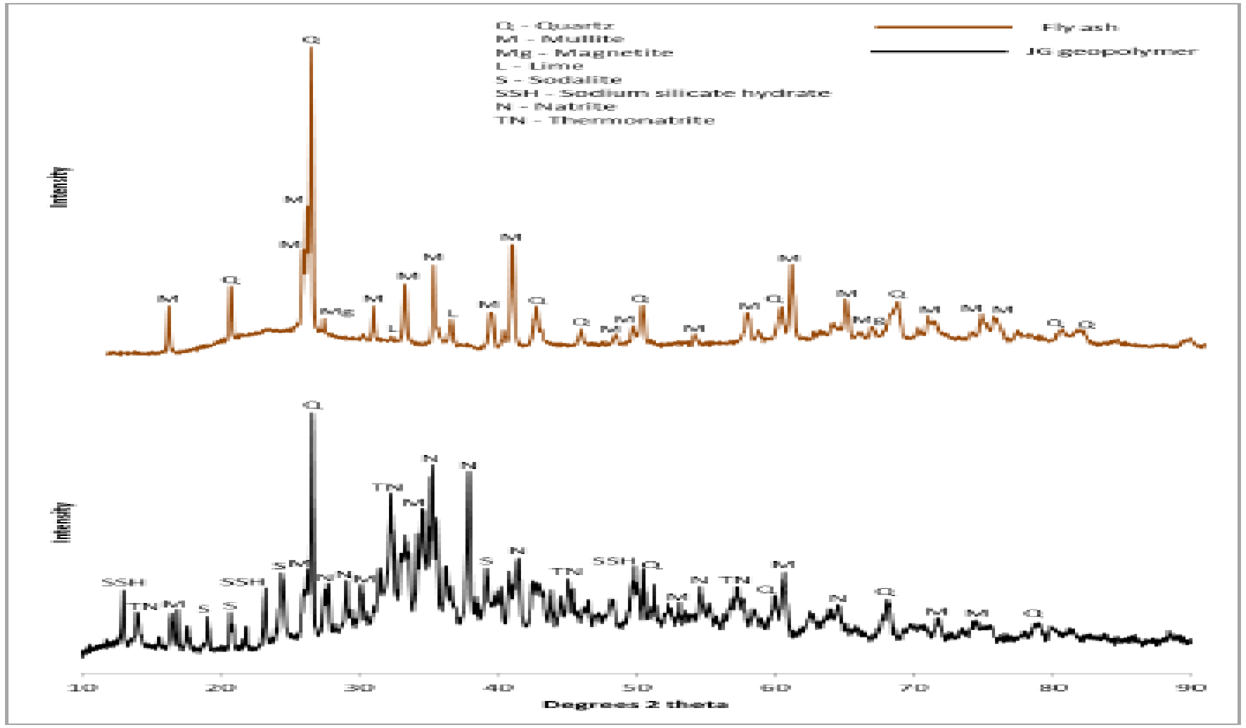


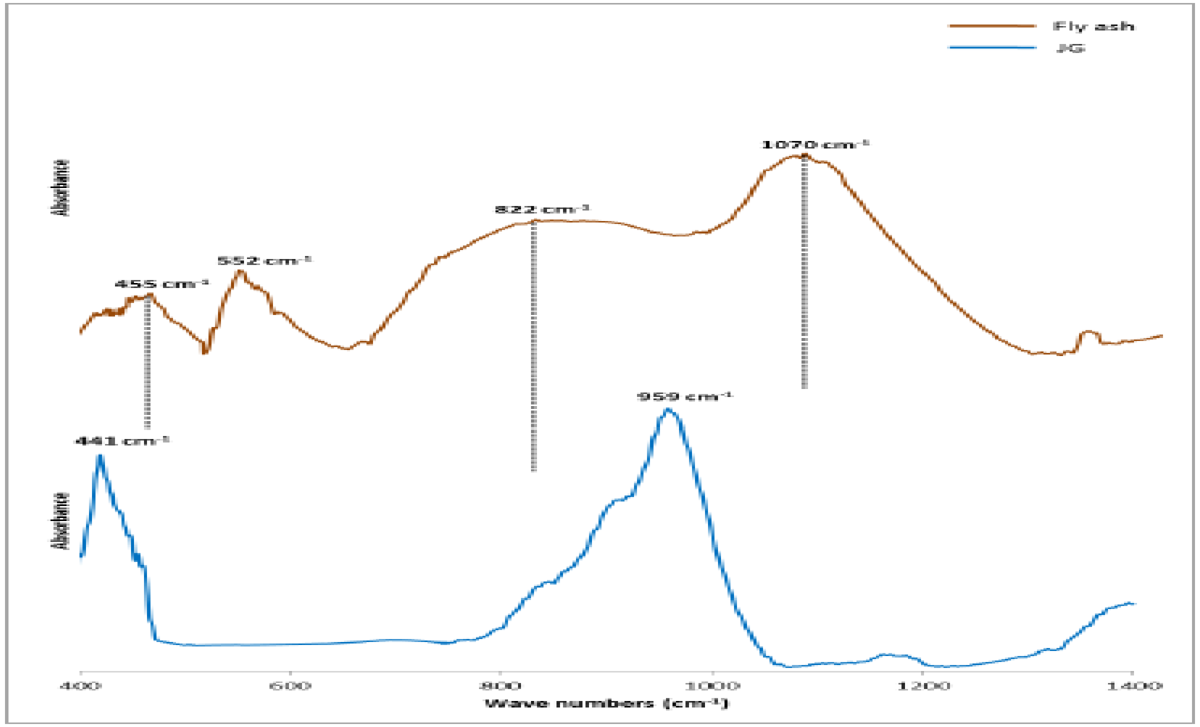


SEM images of freeze-dried slurry samples collected from the jetloop reactor at different time intervals (A=30 min, B=60 min, C=90 min, D=120 min, E=150 min, F=180 min); parameters held constant: fly ash (8 kg), NaOH (8 kg), water (40 litres).

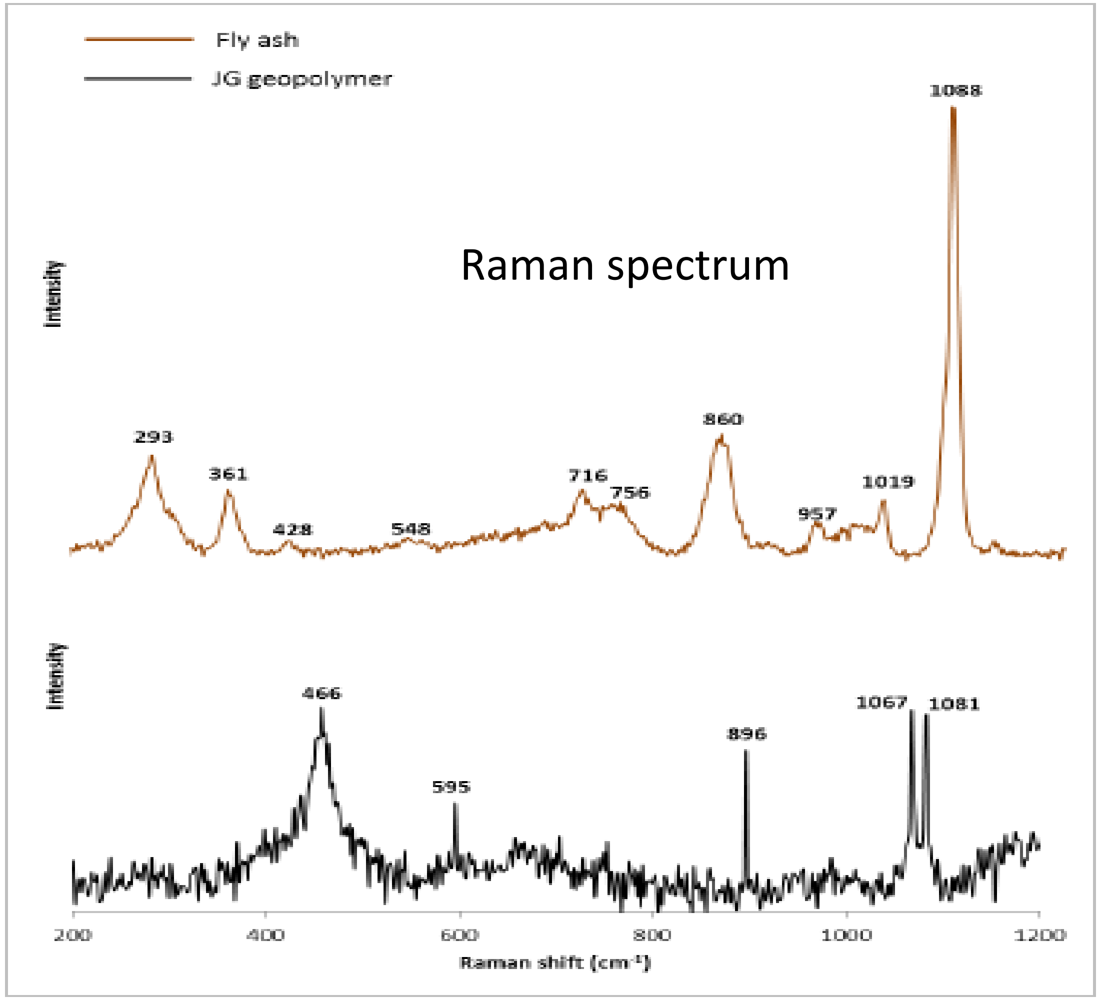
XRD and FTIR

180 min jetloop run; cured at 80 °C for 5 days.

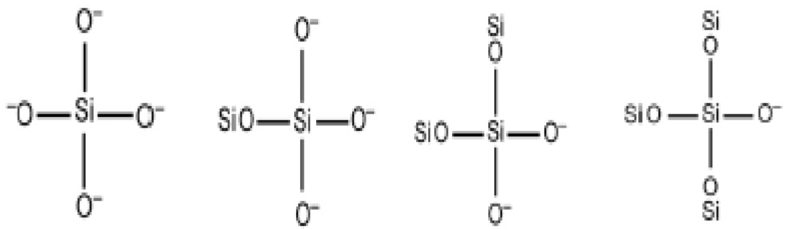




Degree of condensation



Comparison of the degree of condensation of the different geopolymers produced in this study (Raman data)



Silicate structural units	SiO_4	$-SiO_3$	$=SiO_2$	$\equiv SiO$
Number of non-bridging oxygens	4	3	2	1
Fly ash	860 cm^{-1}		957 cm^{-1}, 1019 cm^{-1}	
Foamed geopolymer (FG or FGW)				1062 cm^{-1}
Sodium silicate geopolymer (SG)			993 cm^{-1}, 1017 cm^{-1}	
Jetloop-assisted geopolymer (JG)		896 cm^{-1}		1067 cm^{-1}

Comparison of products

	Porosity	Density
Foamed geopolymer	26.56 %	1.72 g/cm^3
Sodium silicate geopolymer	3.33 %	2.20 g/cm^3
Jetloop-assisted geopolymer	4.72 %	2.30 g/cm^3
	Compressive strength	**Leaching capability**
Foamed geopolymer	11.38 MPa	0.09 - 9.72 %
Sodium silicate geopolymer	19.59 MPa	0.06 - 9.01 %
Jetloop-assisted geopolymer	n/a	0.15 - 12.56 %
	Amorphous glassy silicate content	
Foamed geopolymer	64.55 mass %	
Sodium silicate geopolymer	66.21 mass %	
Jetloop-assisted geopolymer	73.18 mass %	

Study 2: Geopolymer without aggregate or sand

FA

Alkaline activator

Water

Formulation development

Mixing

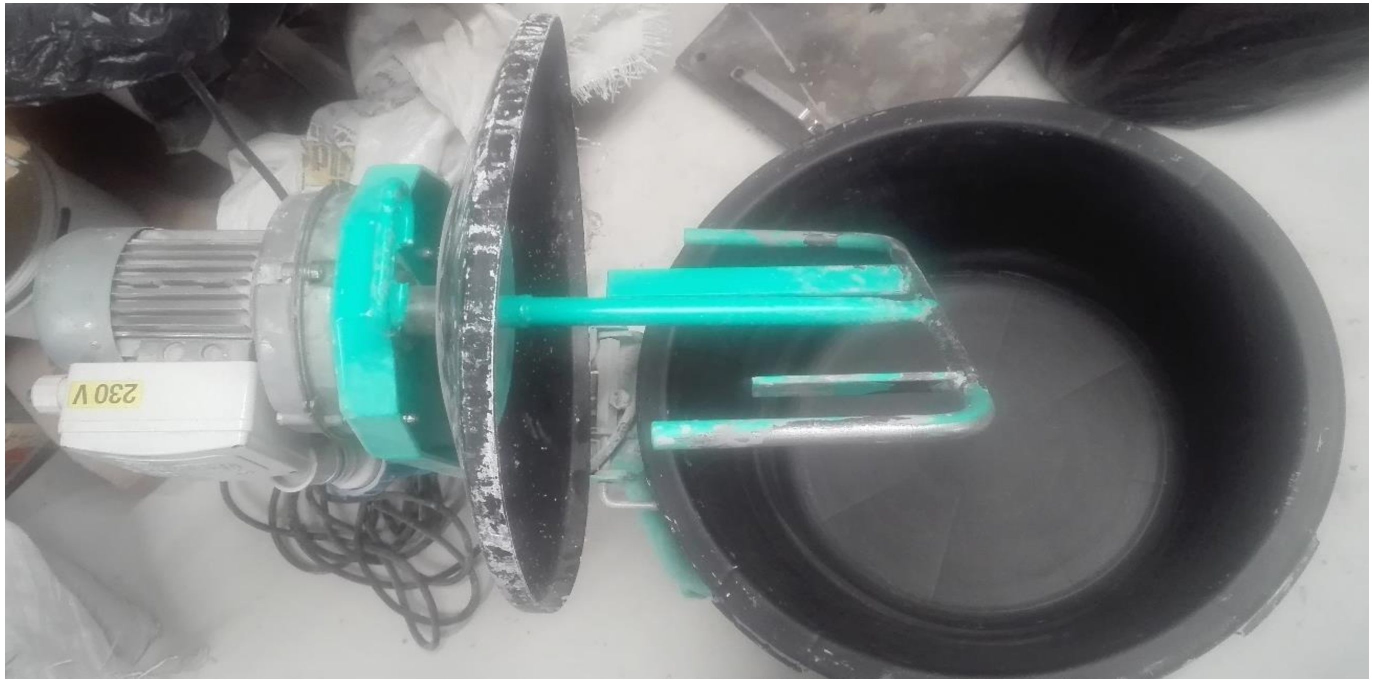
Moulding

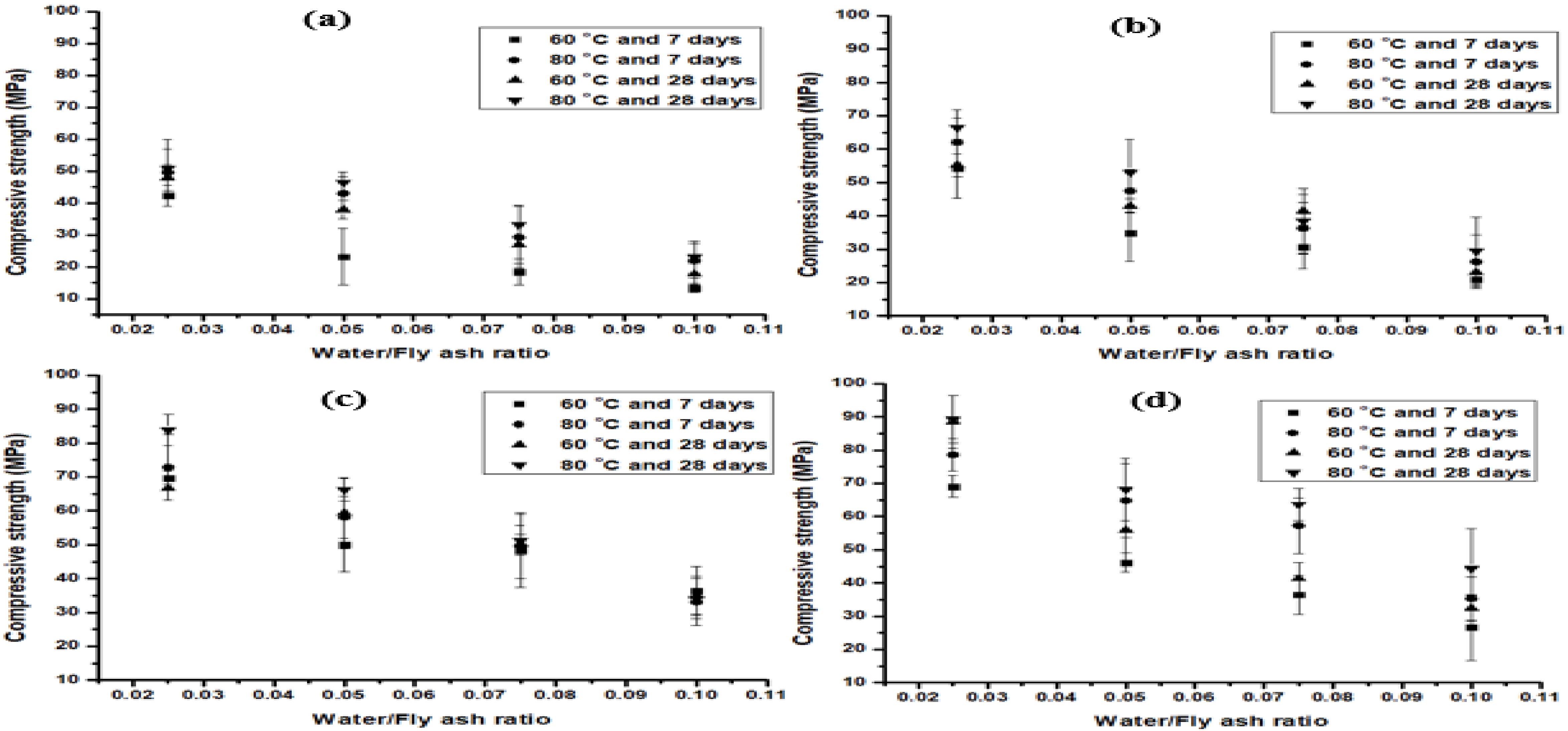
Temperature: T_1 (^OC) | T_2 (^OC)

Aging period: t_1 (days) | t_2 (days)

Geoploymers

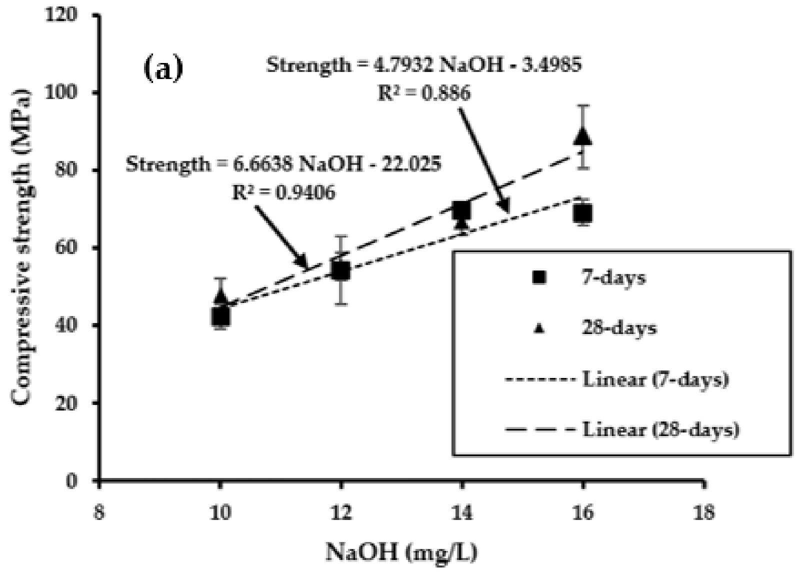
Rosicky Kalombe

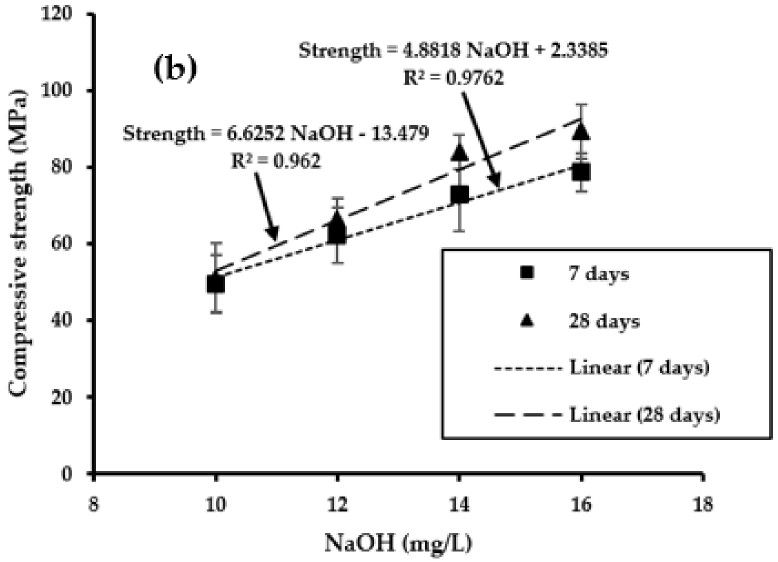




Fly ash-based geopolymer activated with (a) 10, (b) 12, (c) 14, and (d) 16 M of NaOH

SANS 1058:2012 for concrete paving blocks, class 30, which indicates a compressive strength of 30 MPa, and class 40, with a compressive strength of 40 MPa. The water absorption should fall within the range of 6.5% and 8%





Regression model obtained using the compressive strength versus NaOH concentration of geopolymer cured at (a) 60 °C, and (b) 80 °C.

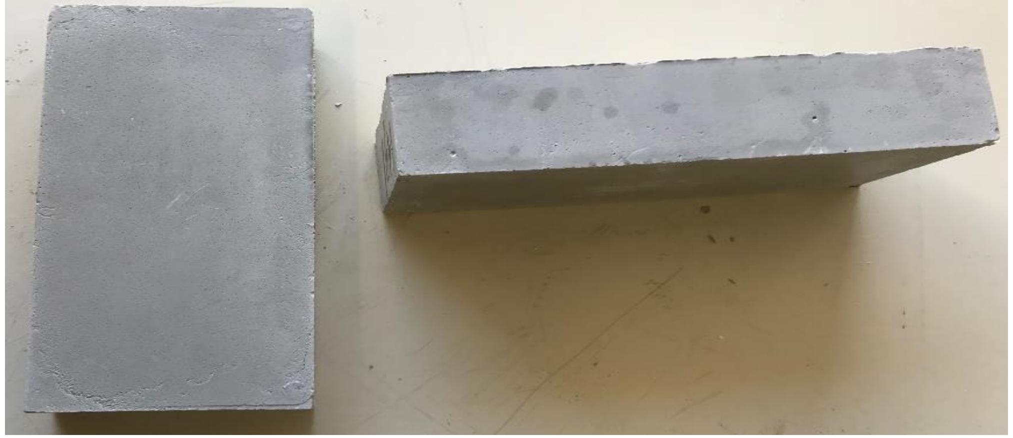
Water absorption of fly ash-based geopolymer products

NaOH (M)	Compressive Strength (MPa)	Water Absorption (%)
10	47.98 ± 4.15	7.55 ± 0.17
12	55.21 ± 3.41	4.79 ± 0.20
14	66.64 ± 3.43	4.39 ± 0.83
16	88.59 ± 7.97	3.74 ± 0.78

Products could be made and used within 7 or 28 days, because they would have a compressive strength of up to 90 MPa

The water absorption should fall within the range of 6.5% and 8%

Paving bricks average mass 2.13±0.1 kg



Ave compressive strength of 49.66±7.4 MPa

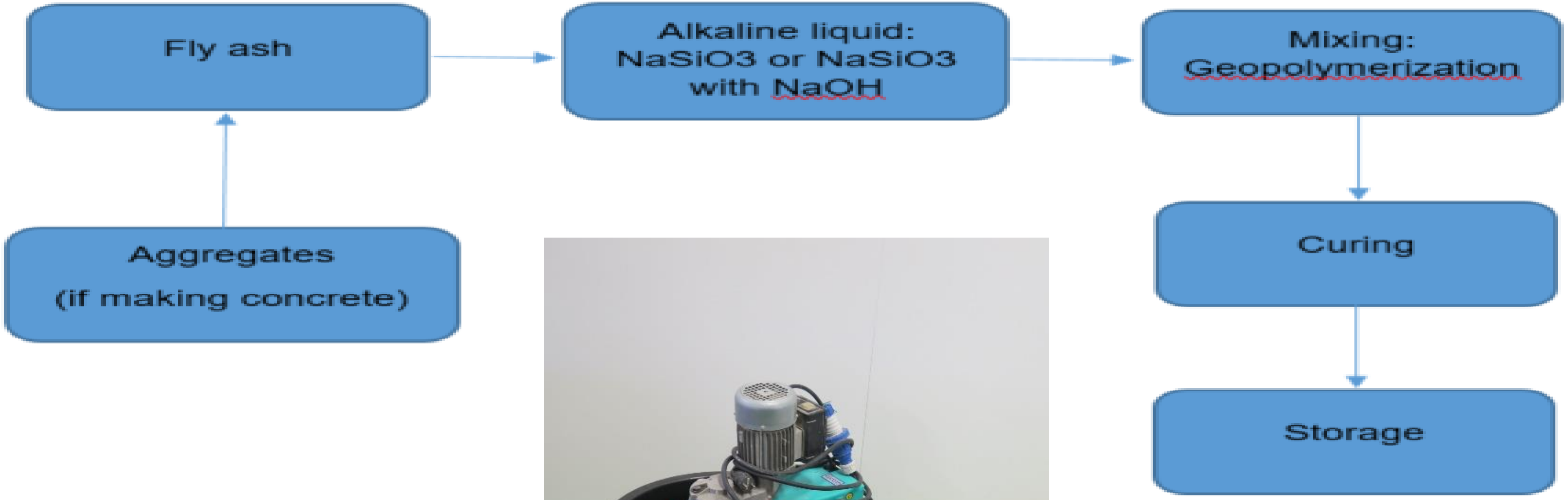
PRODUCTION COSTS

Cost item	Plant capacity	
	5 460 kg/year	**152 880 kg/year**
Fixed capital investment	R 130 548	R 863 907.72
Raw materials costs	R 4 431.34	R 118 536.86
Utilities costs	R 5 596.69	R 7 693.37
Operating labour costs	R 111 852	R 223 704
Production cost R/kg	R 50.33/kg	R 5.57/kg

Rooftile average mass 3.33±0.15 kg and overall size of 290 x 214 mm

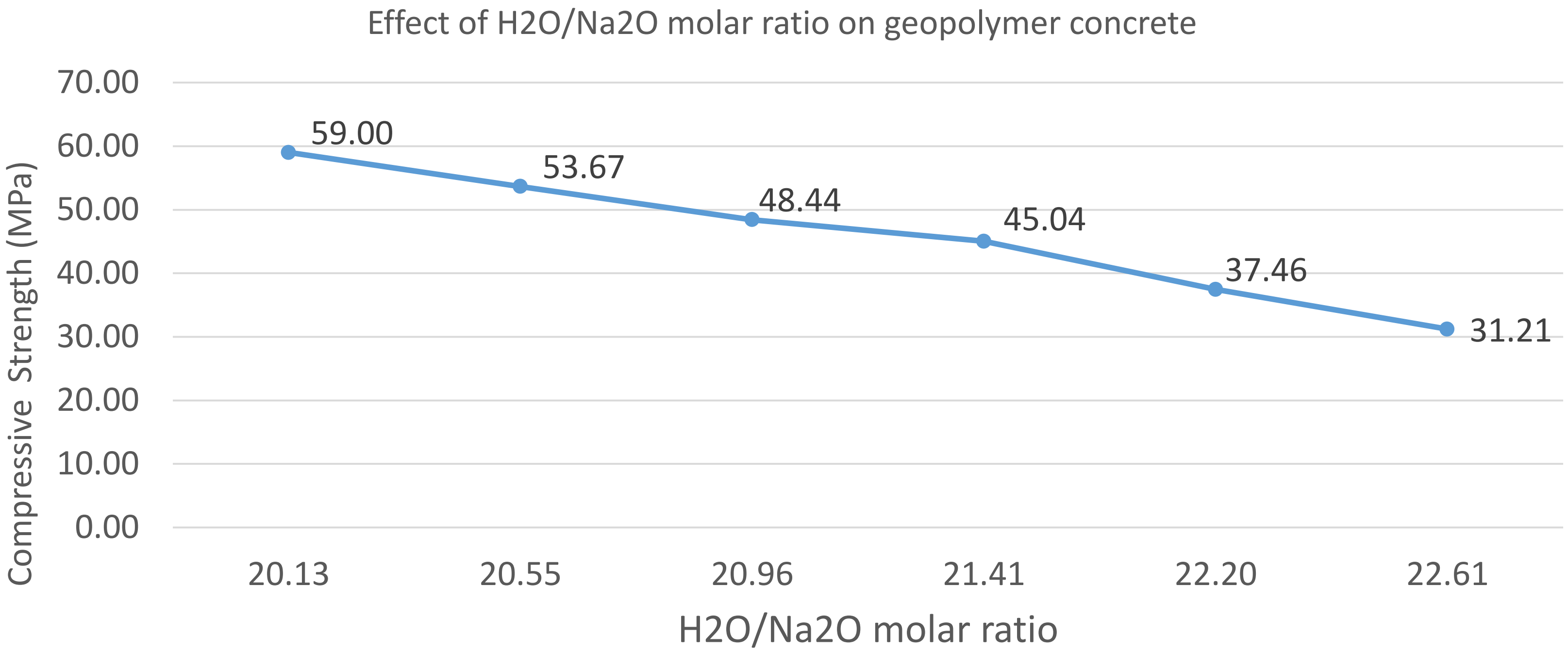
A large amount of coal fly ash can be used in the synthesis of geopolymer (up to 73 %)

Study 3: Geopolymer with aggregate and sand



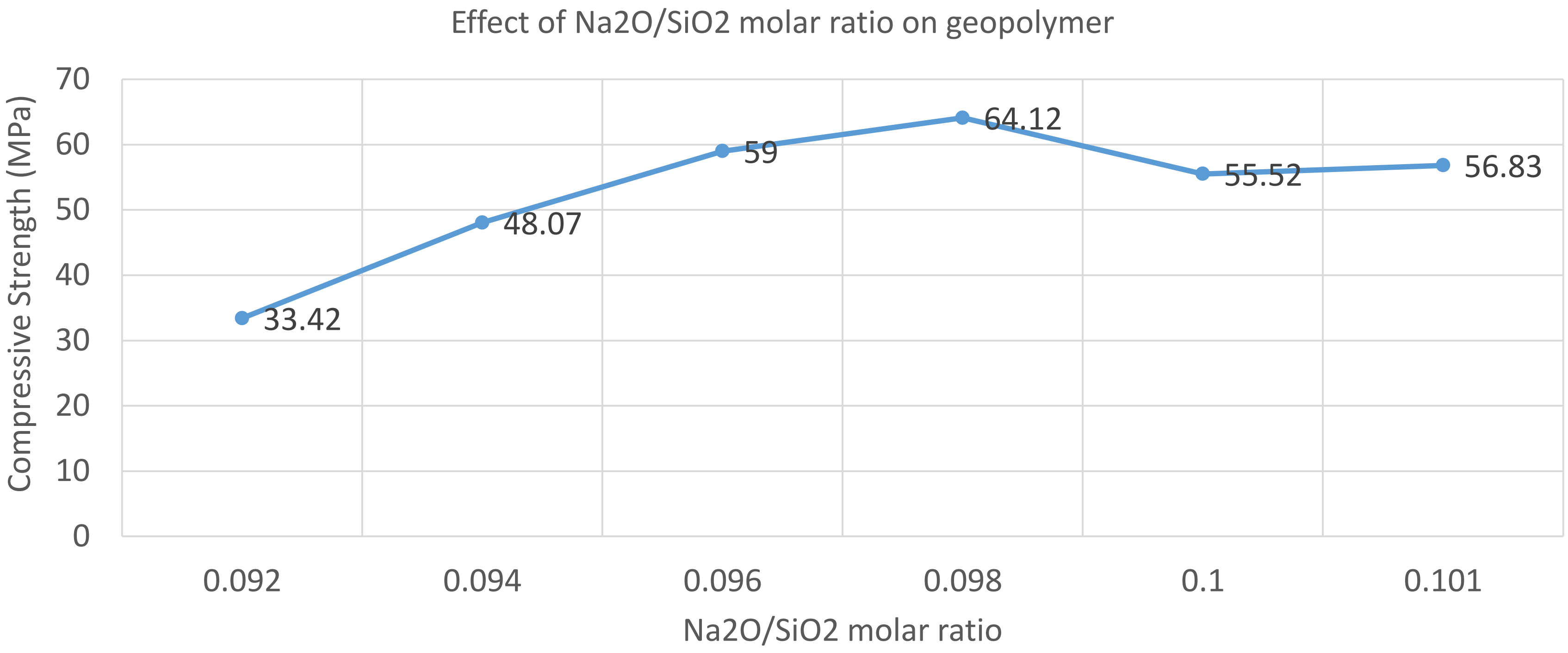
Fidele Ntahinta

Study 3: Results



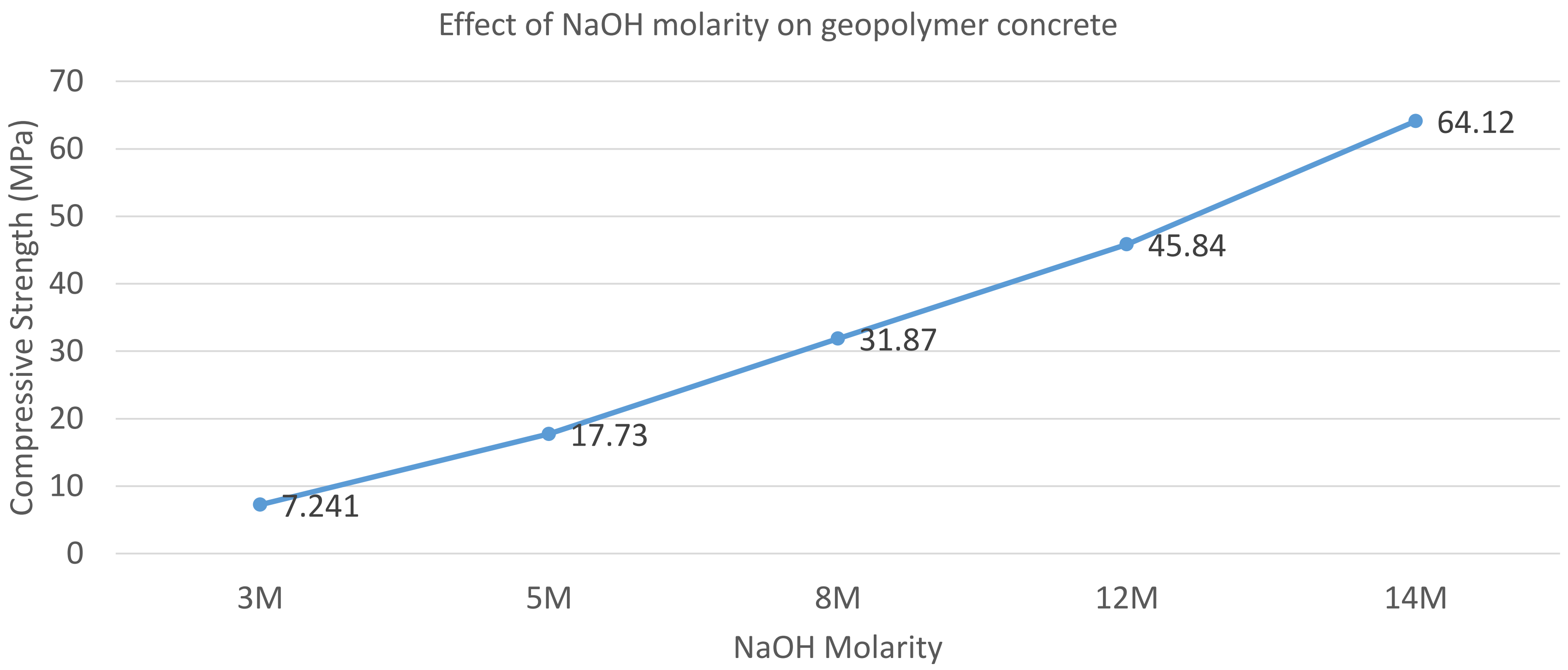
Mixture	H_2O/Na_2O	Average maximum compressive Strength (MPa)	Standard deviation
4	20.13	59.00	3.61
3	20.55	53.67	3.45
2	20.96	48.44	6.17
1	21.41	45.04	3.15
5	22.20	37.46	2.64
6	22.61	31.21	1.15

Study 3: Results



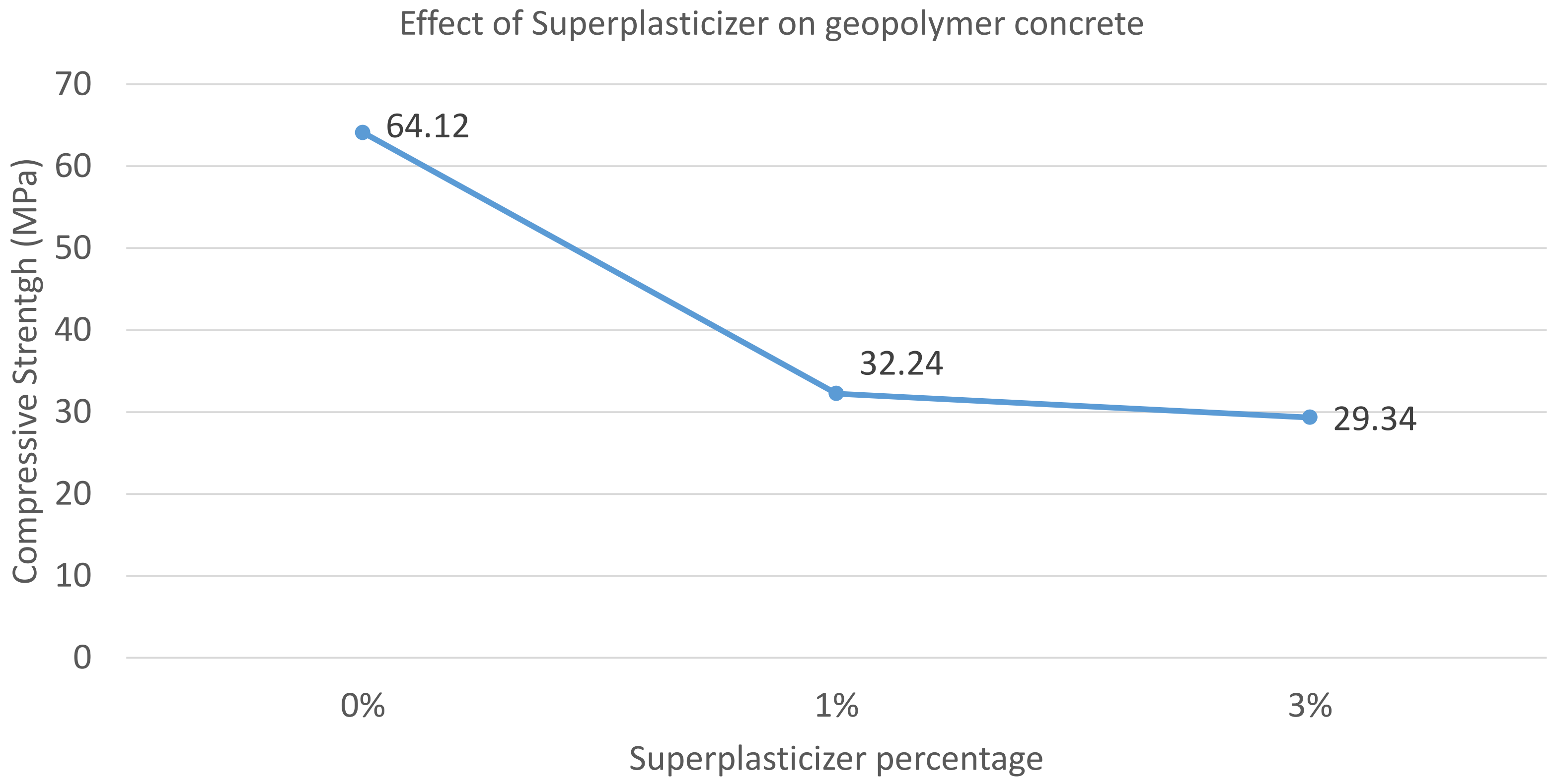
Mixture	Na_2O/SiO_2 ratio	Average maximum compressive Strength (MPa)	Standard deviation
11	0.092	33.42	3.49
10	0.094	48.07	1.45
4	0.096	59	3.61
7	0.098	64.12	1.34
8	0.1	55.52	1.81
9	0.101	56.83	2.74

Study 3: Results



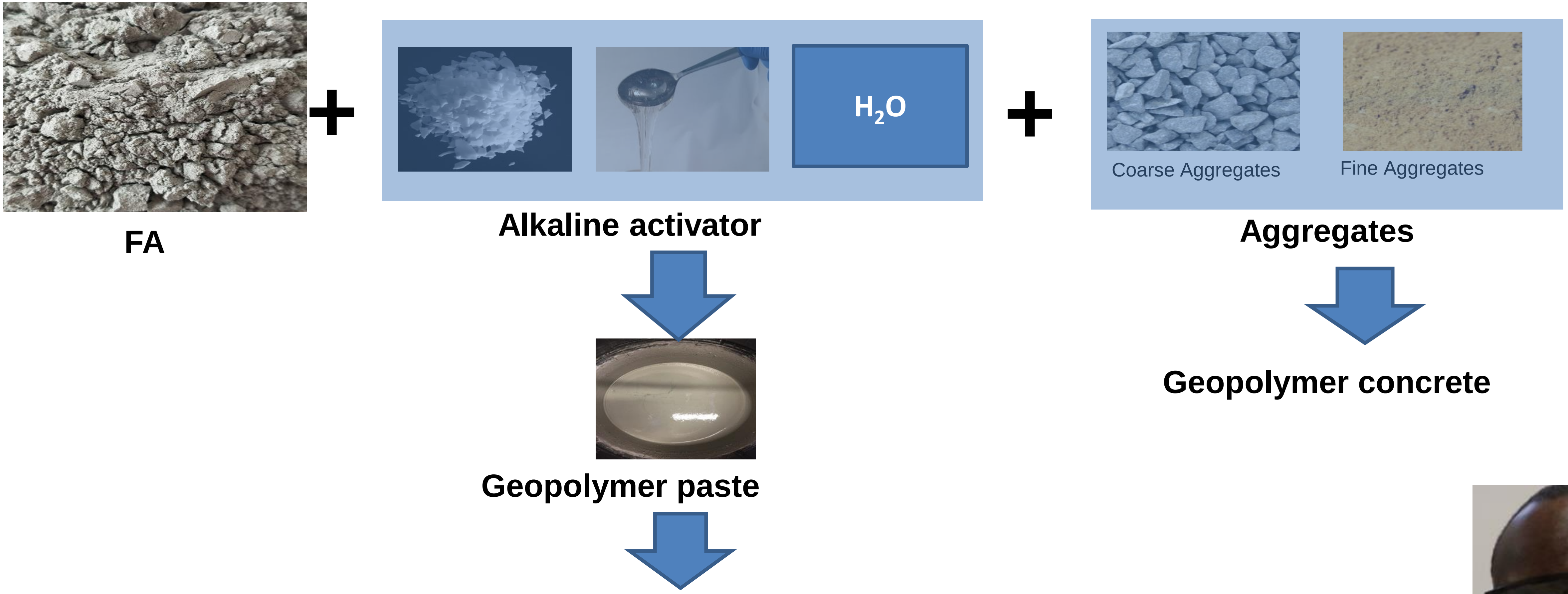
Mixture	NaOH Concentration	Average maximum compressive strength (Mpa)	Standard deviation
15	3M	7.241	1.34
14	5M	17.73	2.60
13	8M	31.87	0.49
12	12M	45.84	1.53
7	14M	64.12	2.67

Study 3: Results



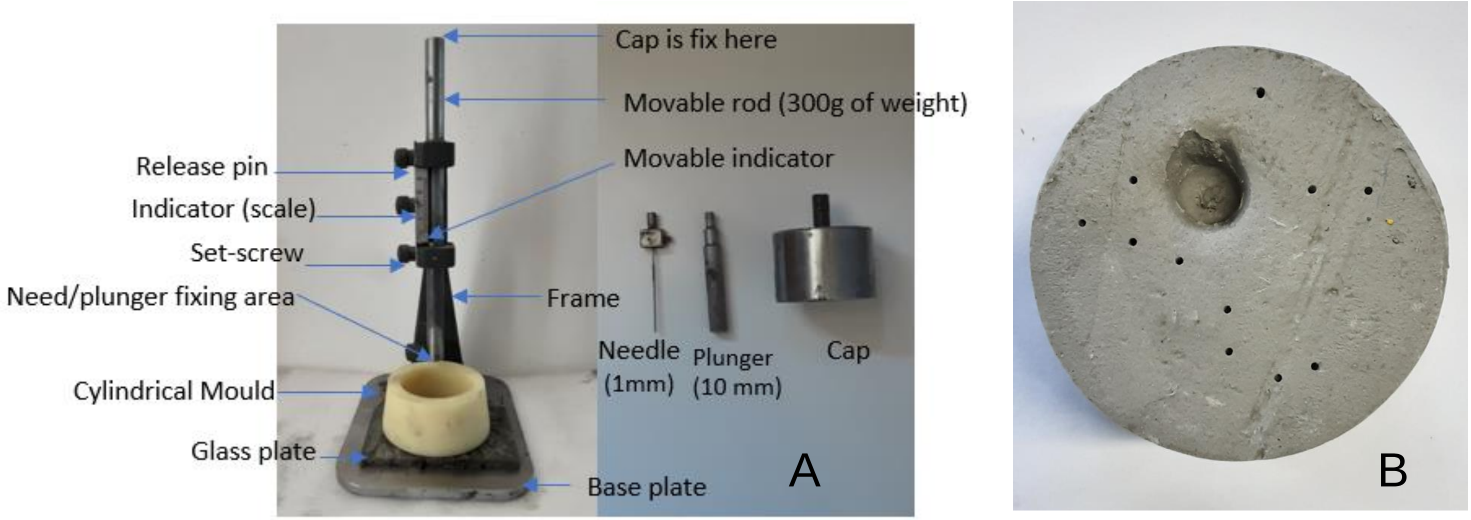
Mixture	Superplasticizer percentage	Average maximum compressive strength (MPa)	Standard deviation
7	0%	64.12	1.34
21	1%	32.24	3.54
22	3%	29.34	2.76

Study 4: Geopolymer Paste and Concrete

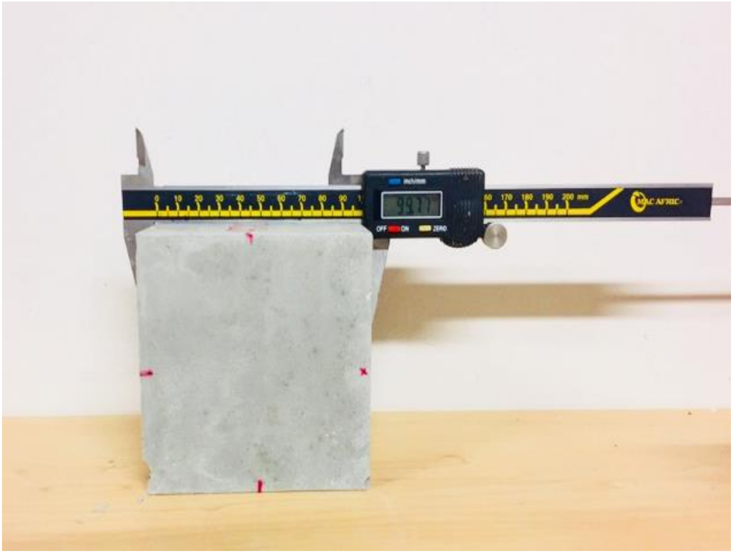


Evral Ntsa

Setting times and shrinkage



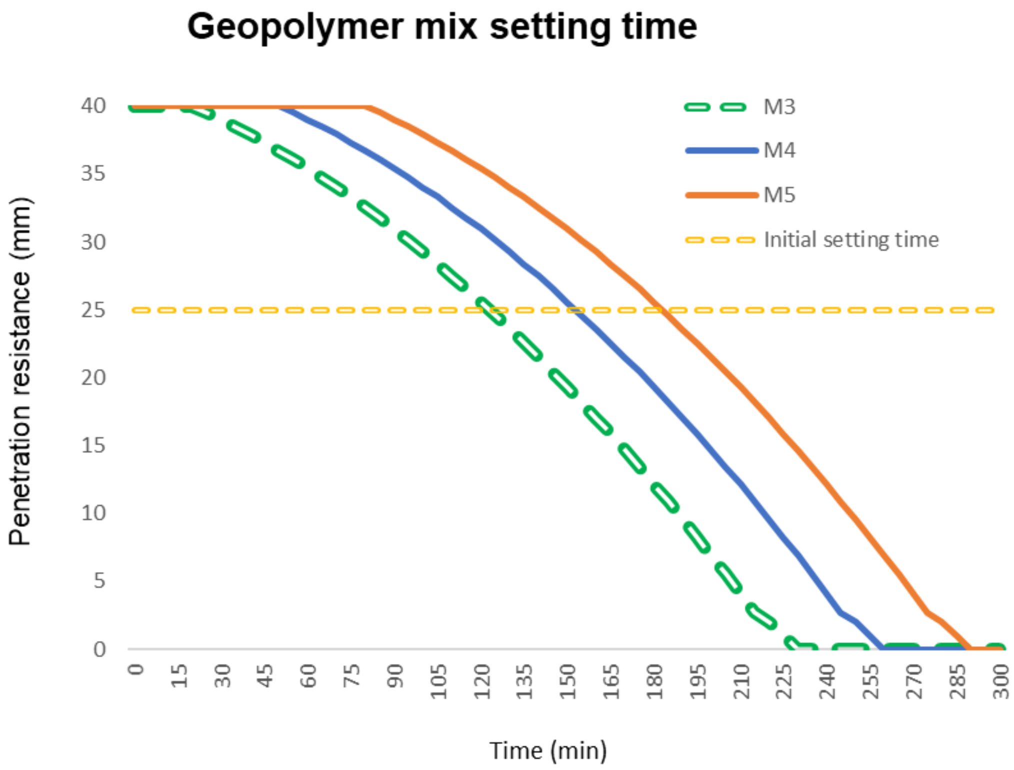
Vicat apparatus (A) and sample after test (B)



Setting times carried out under room temperature at a range of 25 – 27°C

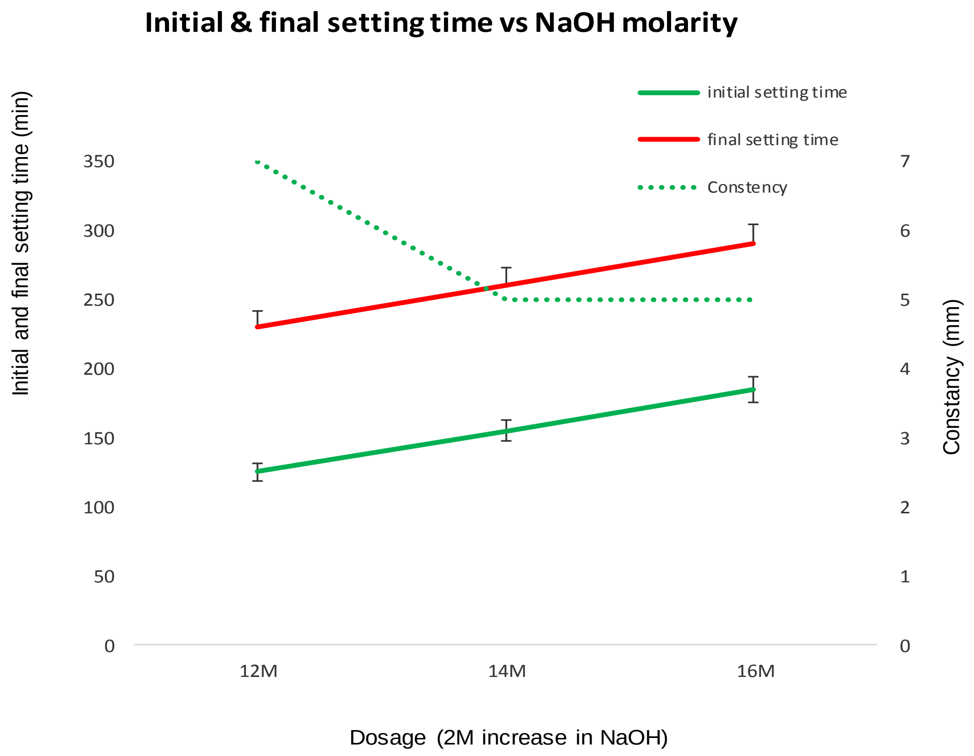
Geopolymer paste tested for initial and final setting time according to ASTM C 191: 2018 (Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle) which is the same as the national standard method SANS 50196-3:2006 part 6 (30% of water was used as w/b ratio) using the Vicat apparatus

Initial and final setting time of M1,M2 and M3 geopolymer pastes

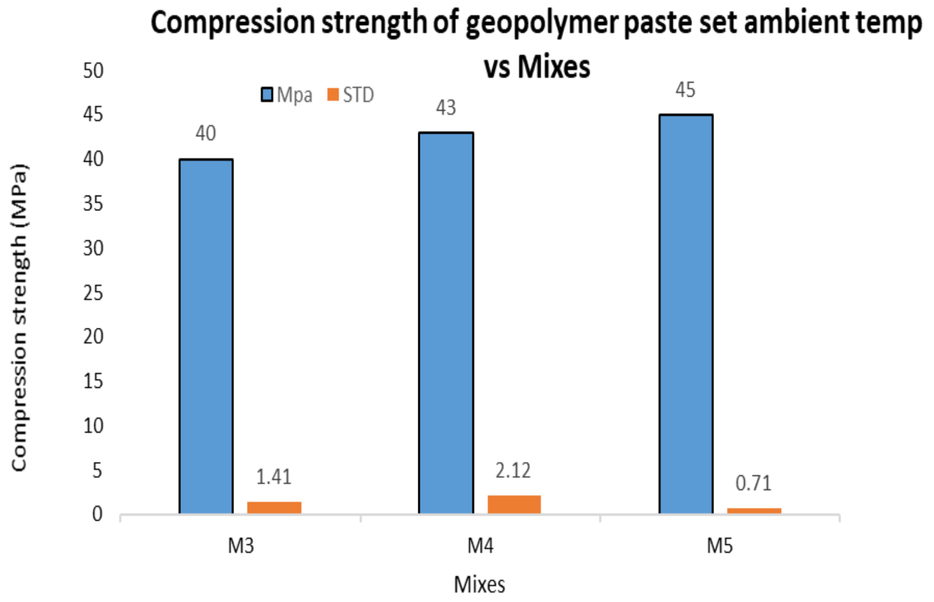


set at ambient temperature with final setting time of 3.8 to 4.5 hr

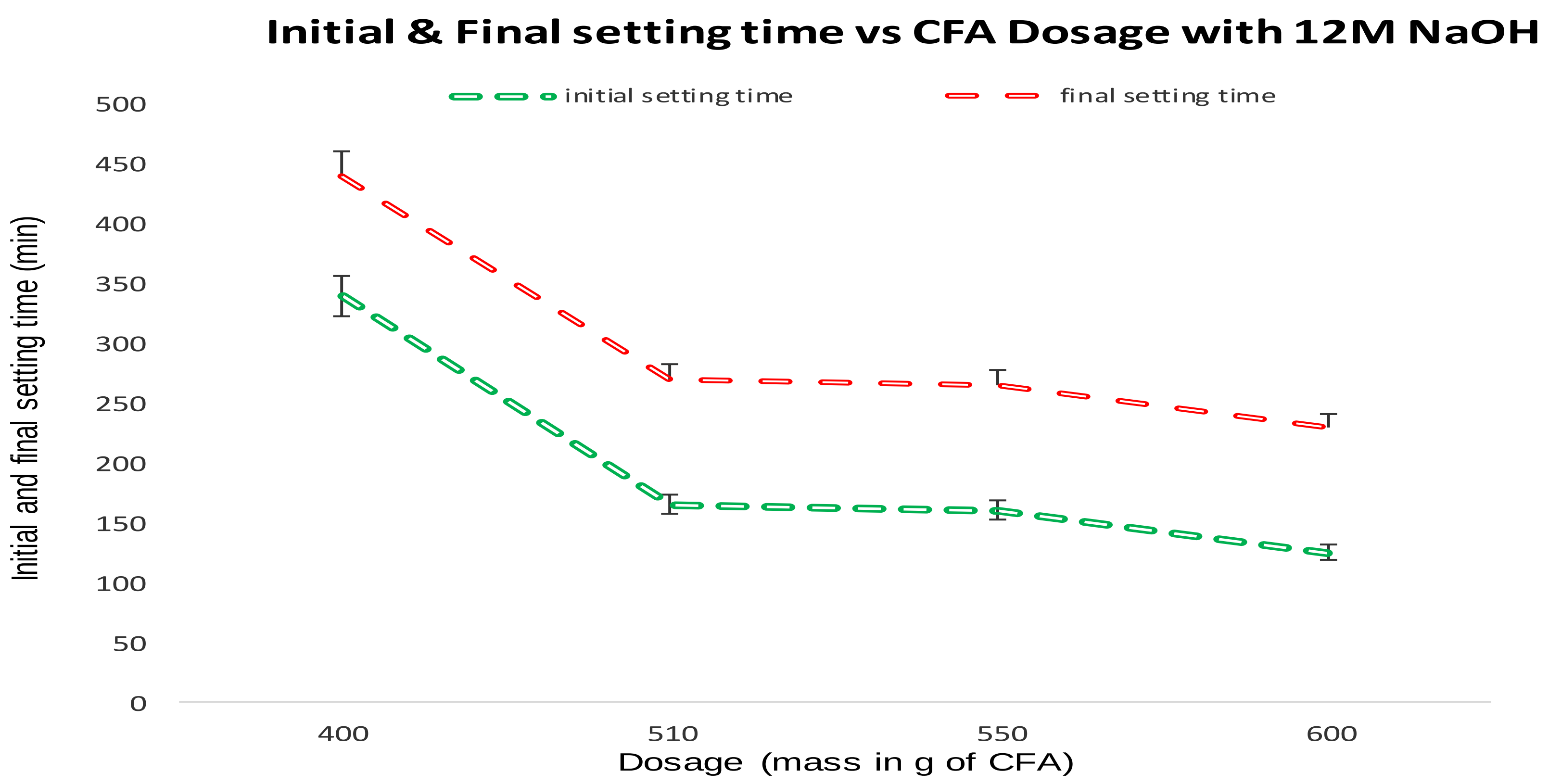
Geopolymer paste setting time and strength development



Ambient temperature at 48 days



Effect of CFA dose on initial and final setting time on geopolymer paste



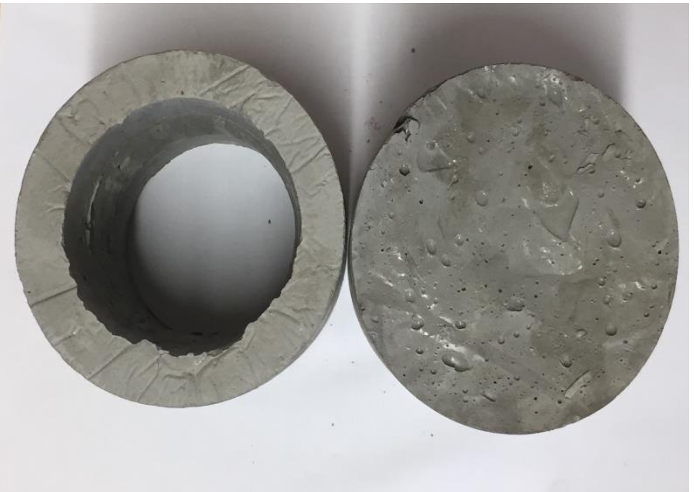
Strength requirements for masonry units and

The compressive strength of concrete and clay masonry units internationally used for building and construction purposes range between 1000 psi (6.9 MPa) and 14400 psi (99.3 MPa) (Portland Cement Association, 1993).

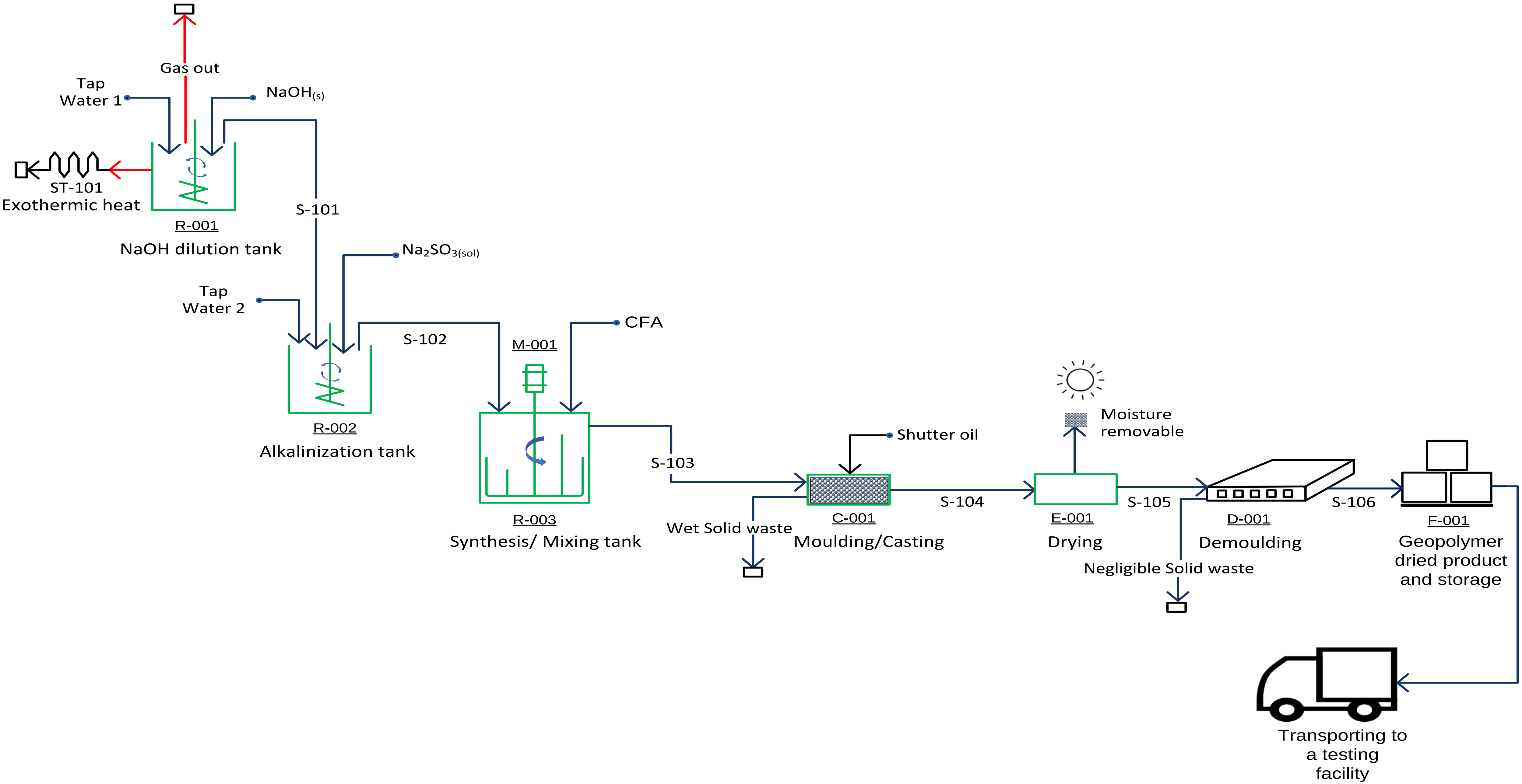
Wall type	Position	Minimum average compressive strength (MPa)		Class of mortar required
		Solid units	Hollow units	
Structural other than foundation and retaining walls	Single storey building - internal or external	7.0	3.5	II
	Double storey building - internal or external	10.5 or 14.0	7.0	II
Non-structural other than parapet, balustrade and free-standing walls	External	7.0	3.5	II
	Internal	7.0	3.5	III
Free-standing	External or internal	10.5	7.0	II
Foundation	Supporting single storey	7.0	3.5	II
Foundation	Supporting double storey	10.5 or 14.0	7.0	II
Parapet	-	7.0	3.5	II
Balustrade	-	7.0	3.5	II
Retaining	-	10.5	7.0	II

Source: (Clay Brick Association of South Africa, 2012).

PRODUCTS:
Paving bricks, roof tiles, pipes and poles

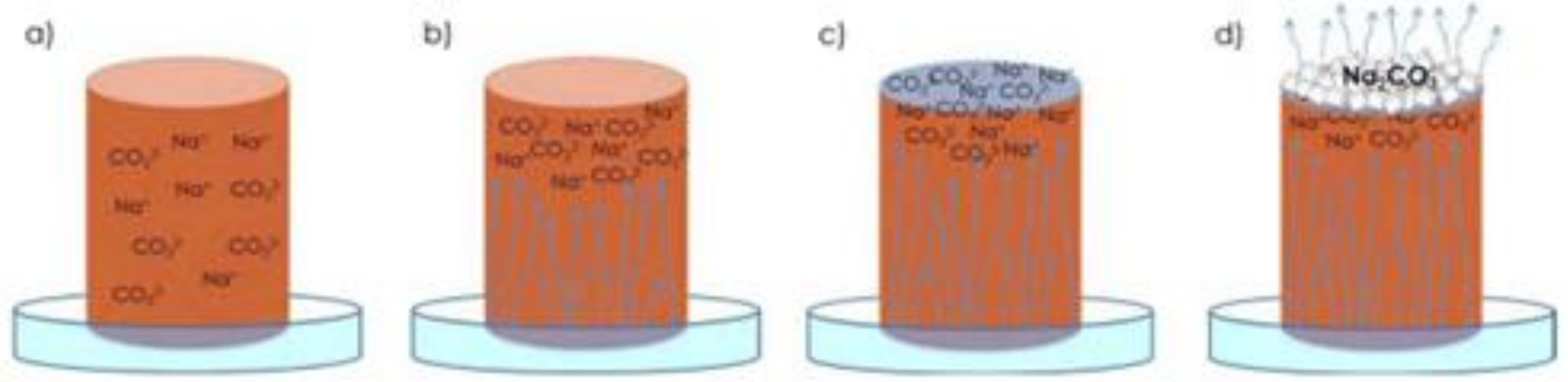


Geopolymer block flow diagram



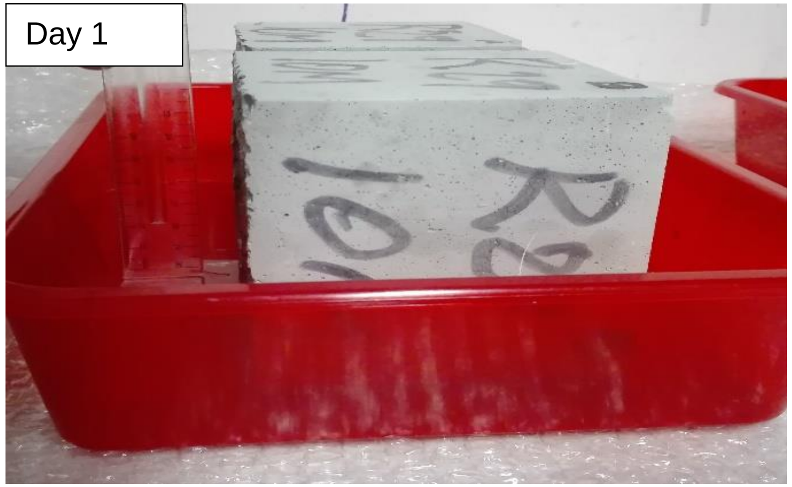
Some things to keep in mind:

Effluorescence



Efflorescence

The build-up of a white layer resulting from the dissolved salts present


Day 1

After 7 days

After 14 days

After 34 days

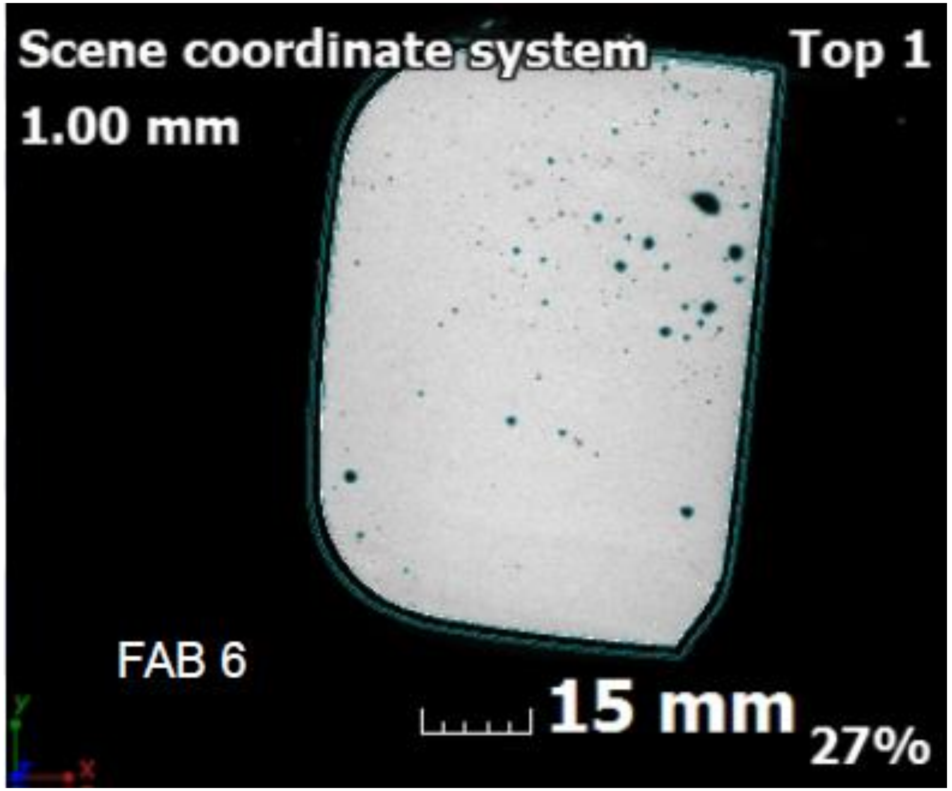
Element	Total elemental content Matla fly ash (mg/kg)	Total elemental content geopolymer (mg/kg)	Matla fly ash L/S 20:1 (mg/kg)	Geopolymer L/S 20:1 (mg/kg)	% Matla fly ash leached	% Geopolymer leached
Si	254850±444	230985±390	2.12±0.02	8.21±1.05	0.0008	0.004
Al	145387±153	140482±267	5.22±0.01	1.42±0.009	0.004	0.001
Fe	40262±245	38373±40	0.19±0.0001	BDL	0.0005	BDL
Ca	38498±109	37087±124	1406.46±1.10	6.42±0.02	3.65	0.02
Mg	8405±70	7690±35	46.4±0.05	0.1±0.003	0.55	0.0014
Na	1484±20	151982±30.81	42.22±0.05	30.81±3.16	2.85	0.02
K	6281±127	4957±127	84.57±0.36	71.54±0.20	1.35	1.44
Sr	959.36±28.06	1095±16.60	4.13±0.003	0.02±5.90	0.33	0.002
Ba	528.38±21.39	967±13.80	0.24±0.0003	0.009±0.001	0.23	0.0009
Zn	104.98±7.25	101.3±2.49	0.02±0.00003	0.058±0.001	0.02	0.06
V	73.54±1.18	72.59±1.20	0.01±0.00006	0.26±0.001	0.02	0.36
Cr	63.16±1.75	62.84±5.79	0.09±0.0009	BDL	0.14	BDL
As	23.90±3.48	20.53±2.08	0.22±0.001	BDL	0.91	BDL
Pb	22.66±1.85	21.89±1.30	0.02±0.0002	BDL	0.11	BDL
Co	13.31±0.48	13.75±0.55	0.009±0.00002	0.01±0.00005	0.07	0.11
Hg	8.33±0.21	7.74±0.03	0.62±0.003	BDL	7.43	BDL

CO2 emissions savings

Cement or fly ash:
materials required for the construction of a two-room structure per quantity of CO_2 emission.

Cement Brick			**Fly Ash Brick**		
Material		**CO_2 Emission**	**Material**		**CO_2 Emission**
	(kg)			**(kg)**	
Cement	5397	4696	Fly ash	21258	255
Sand	32387	324	NaOH	2126	1126
Water	3238	16	Na_2SiO_3	5315	2253
			Water	2126	11
Total	41022	5036		30824	3645

Computer Tomography Analysis



With the CT imaging, the interior of the samples can be seen.

This is important to see whether the samples are of porous nature

Neutron Activation Analysis

39 elements determined by Neutron Activation Analysis: Na, Al, Cl, K, Sc, Ca, Ti, Cr, V, Mn, Ni, Fe, Co, Zn, Se, As, Br, Sr, Rb, Mo, Sb, Ba, Cs, La, Ce, Nd, Eu, Sm, Tb, Dy, Yb, Tm, Hf, Ta, W, Au, Th, and U

Th and U concentrations in the fly ashes were similar to values found in literature and leaching did not reduce this

The concentrations of U and Th in Fly ash bricks and geopolymers are similar to the concentrations of Lethabo fly ash

Notes	Th	U
Matla Fly Ash	43,6	11,8
Lethabo Fly Ash	44,5	12,8
Matla Leached 10:1 - 1	44,8	12,1
Matla Leached 10:1 - 2	44,5	11,6
Matla Leached 10:1 - 3	43,7	11,2
Matla Leached 20:1 - 1	44,7	11,7
Matla Leached 20:1 - 2	43,9	11,7
Matla Leached 20:1 - 3	44,3	11,6
Lethabo Leached 10:1 - 1	44,1	12,6
Lethabo Leached 10:1 - 2	44,3	12,8
Lethabo Leached 10:1 - 3	44	12,6
Lethabo Leached 20:1 - 1	43,5	12,5
Lethabo Leached 20:1 - 2	43,3	12,5
Lethabo Leached 20:1 - 3	42,7	12,1
PPC IDM Cement	3,59	1,75
Commercial Brick	4,01	0,927
Commercial Block	9,14	2,68
Commercial Stone	15,6	4,27
Commercial Sand	2,18	1,09
ENS Brick 1	40,6	14,1
ENS Brick 2	39,7	13,3
ENS Brick 3	41,4	15,1
ENS Brick 4	40,5	14,2
ENS Brick 5	41,1	14,2
ENS Brick 6	40,3	14,2
ENS Brick 7	40,1	14,3
ENS Brick 8	39,2	13,7
ENS Brick 9	36,8	13,1
G4	38,6	14,5
G7	39,2	13,5
G8	39,1	13,7
G9	37,5	13,6
G12	36,8	12,1
Concrete 8	19,4	6,09

Naturally-Occurring Radioactive Materials (NORMS)

- Fly ash is composed of silica, alumina, heavy metals, rare earth elements and NORM. (^{238}U, ^{235}U, ^{232}Th, ^{226}Ra, ^{40}K, ^{210}Pb, ^{222}Rn).
- Due to the decay of the unstable radionuclides high gamma doses, higher radon exhalation rates results in an overall increase in the radiological hazards
- The radiation in dwellings and other structures, built with materials containing fly ash, can be more intensive than the natural background
- Problem for products where humans are exposed daily
- Tested Matla Fly Ash, Lethabo Fly Ash, geopolymer bricks (ENS) (with different % FA content) compared to commercial bricks

Radon and Thoron Measurements

- Radon is a radioactive gas that is produced from radioactive decay of radium,
- Radon has a $t_{1/2}$ = 3.82 days, thoron has a $t_{1/2}$ = 56 s.
- Radon produces radioactive isotopes or alpha particles as it decays, most importantly Po-214 and Po-218 with short half-life of 3,05 min and 164 microseconds respectively.
- Radon-220 (thoron) decays from thorium-232 decay chain.
- Radon-222 (radon) decays from uranium-238 and is always detectable.
- Rn-222 → Po-218 → Pb-214 → Po-214 → Pb-210 (stable) – this is a radon-220 chain with just the radioactive gases and short-lived progeny.
- Rn-220 → Po-216 → Pb-212 → Bi-212 → (34%) Thallium-208) → Pb-208
  → (66%) Po-212 → Pb-208

RAD7 uses a solid-state alpha detector and converts alpha radiation directly to an electrical signal.

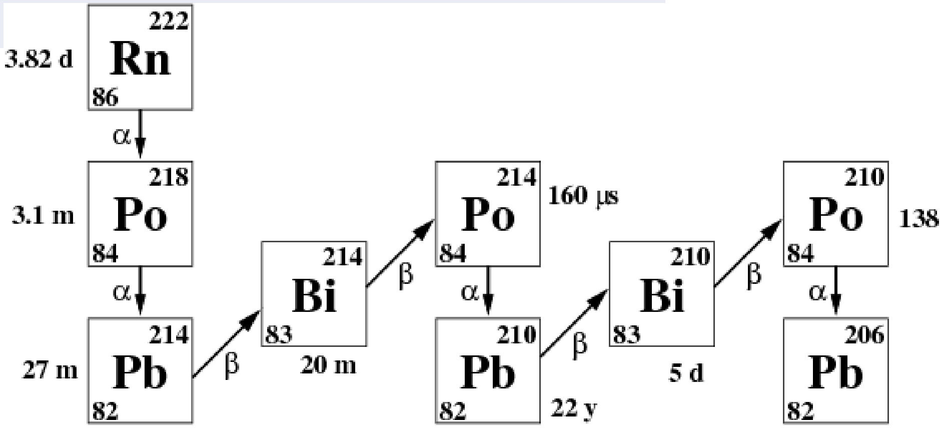
Detector uses Po-218 signal to determine radon concentration and Po-216 to determine thoron concentration

RAD7 Detector

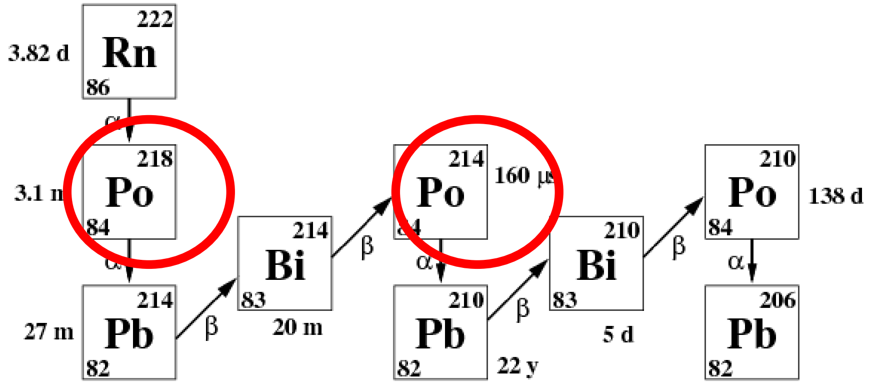
Sample	Representative radon activity concentration (Bq/m³)	Representative thoron activity concentration (Bq/m³)
Matla Fly Ash	16,7 ± 4	10,5 ± 4,5
PPC IDM Cement	34,7 ± 5,8	7,21 ± 3,7
Commercial Brick	96,8 ± 10	51,9 ± 10
Commercial Block	29,5 ± 5,3	49,9 ± 10
Concrete 8	14,4 ± 3,7	30,6 ± 8
G4	143 ± 12	184 ± 19
G7	198 ± 14	333 ± 25
G8	132 ± 11	140 ± 16
G9	149 ± 12	377 ± 27
G12	157 ± 12	194 ± 19
Blank (2 Cycles)	3,26 ± 2,5	0,8 ± 1,7

The spectra of geopolymer samples G4, G7, G12 showed build-up profiles

Even after 48 recycles, the spectra showed no sign of equilibrium.
Samples (G4 and G7) run for 80 recycles (total of 160 hours).
Equilibrium not reached after 160 hours for G4



Hazards



- radon is the second largest cause of lung cancer in the world and is responsible for approximately 3-14% of lung cancer deaths. (WHO, 2009)
- evidence of the association between indoor radon exposure and lung cancer, even at low radon levels
- radon progeny are metals by their chemical nature and will attach to the surfaces of the lungs and internal organs
- ^{214}Po and ^{218}Po, found in the ^{222}Rn decay chain, are short-lived, radioactive and undergo alpha decay,
- these progeny from radon decay attach to the lungs when inhaled and give the bronchi a significant radiation dose
- International Commission on Radiological Protection (ICRP) recommends allowed indoor radon concentrations of 200-300 Bq/m^3 and 50-1500 Bq/m^3 for work places BUT no known threshold concentration for which radon is not a risk.

Conclusions

The findings can change the perception of coal fly ash from waste to a resource that can be use in the manufacturing of various building materials.

The novelty of this study consisted of: (1) the developed formulations, and (2) the final product quality and characteristics, and applications in the construction industry.

These formulations could be a feasible remediation for several problems, including:

- The reuse of coal fly ash as the main source of silica, alumina, and lime, thus resolving the disposal problem of coal-fired power station plant waste
- No need for the addition of cement or aggregates to the geopolymer, reduces mass and carbon footprint of cement manufacturing
- No need for high temperature kilning
- Replacement of cement with coal fly ash in the construction industry
- Minimum addition of alkaline activators - depends on strength requirements
- Reduced cost of geopolymerization process
- Do not use Fly ash geopolymer products for housing due to NORM content and radon exhalations

Publications

Kalombe, R.M.; Ojumu, V.T.; Eze, C.P.; Nyale, S.M.; Kevern, J; Petrik, L.F. 2020. "Fly Ash-Based Geopolymer Building Materials for Green and Sustainable Development" Materials 13, no. 24: 5699. https://doi.org/10.3390/ma13245699

NDLOVU, N. Z. N., MISSENGUE, R. N. M., PETRIK, L. F. AND OJUMU, T. V. (2017). Synthesis and characterization of faujasite zeolite and geopolymer from South African coal fly ash. ASCE's Journal of Environmental Engineering. Vol. 143, Issue 9 (September 2017). http://ascelibrary.org/doi/full/10.1061/%28ASCE%29EE.1943-7870.0001212

BÖKE, N., GRANT, D. B., NYALE, S. AND PETRIK, L. F. (2015). New synthesis method for the production of coal fly ash-based foamed geopolymers. Construction & Building Materials, 75, pp. 189-199. DOI: 10.1016/j.conbuildmat.2014.07.041.

Thank you for your attention!

Any Questions

Acknowledgements

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