2011 GEOPOLYMER CAMP

4th Session

Geopolymer Cements

ANNAMALAI UNIVERSITY

Workshop

Geopolymer Cement and Concrete

07 December 2010


SEC 2010
THE SEVENTH STRUCTURAL ENGINEERING CONVENTION
PUBLIC LECTURE ON
Why Pharaohs Built the Pyramids with Fake Stones
BY
Dr. JOSEPH DAVIDOVITS
Geopolymer Institute
SAINT-QUENTIN,FRANCE
on 9-12-2010 at 6 pm
AUMTEC HALL,FEAT, ANNAMALAI UNIVERSITY
Organised By
DEPARTMENT OF CIVIL AND STRUCTURAL ENGINEERING
ANNAMALAI UNIVERSITY
ANNAMALAI NAGAR 608 002
SEC 2010
MEGA BUILD EXPO
INTERNATIONAL WORKSHOP
ON
GEOPOLYMER CEMENT AND CONCRETE
7th DECEMBER - 2010
PRE-CONVENTION EVENT OF
STRUCTURAL ENGINEERING CONVENTION - SEC 2010
Organised By
DEPARTMENT OF CIVIL AND STRUCTURAL ENGINEERING
ANNAMALAI UNIVERSITY
ANNAMALAI NAGAR 608 002


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Imperative to find alternative to cement, says French expert

International workshop on 'Geopolymer cement and concrete' held

Special Correspondent

CUDDALORE: Going by the quantum of carbon-dioxide emission, the Portland cement industry is the highest polluting industry in the world. Therefore, more than the developed countries the developing countries that require enormous quantity of cement for infrastructure face acute pollution problem, according to Joseph Davidovits of Geopolymer Institute, France.

Hence, it has become imperative to find an alternative to cement, said Mr. Davidovits, popularly known as "Father of Geopolymer technology." He was participating as chief guest at an international workshop on "Geopolymer cement and concrete" organised by the Department of Civil and Structural Engineering of Annamalai University at Chidambaram on Tuesday.

He opined that India and France that had now signed many pacts on high-technology aspects could have focussed attention on geopolymer technology too because it could be equated to nanotechnology.

Mr. Davidovits, who has coined the term 'geopolymer,' said that although geopolymer technology was considered new it had ancient roots and had been used in the construction of the pyramids at Giza in Egypt.

The production of one tonne of Portland cement generated one tonne of carbon-dioxide. According to statistics, 1.8 billion tonnes of cement were produced in the world in 2000 and it accounted for 1.8 billion tonnes of carbon-dioxide.

Annamalai University Vice Chancellor M.Ramanathan handing over the proceedings of the international workshop on "Geopolymer cement and concrete" to Joseph Davidovits of Geopolymer Institute, France, at Chidambaram on Tuesday.
- PHOTO: C VENKATACHALAPATHY

In developing countries, particularly China, India and Brazil, there was exponential increase in cement production.

Any further economic development in these countries would strongly depend upon creation of more infrastructure and production of more cement. On the contrary, cement production remained constant in the Western countries, particularly in the U.S. and European Union.

The production of one tonne of geopolymer cement would require 3.5 times less energy than that of Portland cement. Therefore, besides deriving cost benefit the geopolymer cement application would also safeguard environment, Mr. Davidovits added. B.Vijaya Rangan of Curtin University of Technology, Perth, Australia, called for transferring the laboratory work on geopolymer to large-scale applications.

M. Ramanathan, Vice-Chancellor of Annamalai University, said that according to statistics 120 million tonnes of coal were burnt in 380 thermal stations in the country during 2006-2007 that generated 108 million tonnes of fly ash.

Hardly 30 million tonnes of fly ash were utilised in the cement and brick industries and the remaining was dumped in ash pond. Using the fly ash in a purposeful manner would also spare vast stretches of land and address the pollution problem, Dr. Ramanathan added.

P.Paramasivam of National University of Singapore, Singapore, B.Palaniappan, Dean, Faculty of Engineering and Technology, Annamalai University, C.Antony Jeyasehar, Head, Department of Civil and Structural Engineering and chairman of organising committee and S.Thirugnanasambandam, secretary, spoke.

Geopolymer
inorganic macromolecules

Geopolymer
inorganic macromolecules

Portland CSH

Geopolymer
inorganic macromolecules

Portland CSH

geopolymer NaASH

Ca-based

Geopolymer cement

Ca-based

Geopolymer cement

chemistry =

Ca-based

Geopolymer cement

chemistry =

alkalination of slag

Alkali-activation : first 2 steps of

Geopolymerization *in alkaline milieu*

1. alkalination: alumino-silicates + alkali

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Geopolymerization *in alkaline milieu*

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2. Depolymerisation of silicates into

   oligomers (oligo-sialates, oligo-siloxo)

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5. Reticulation, networking

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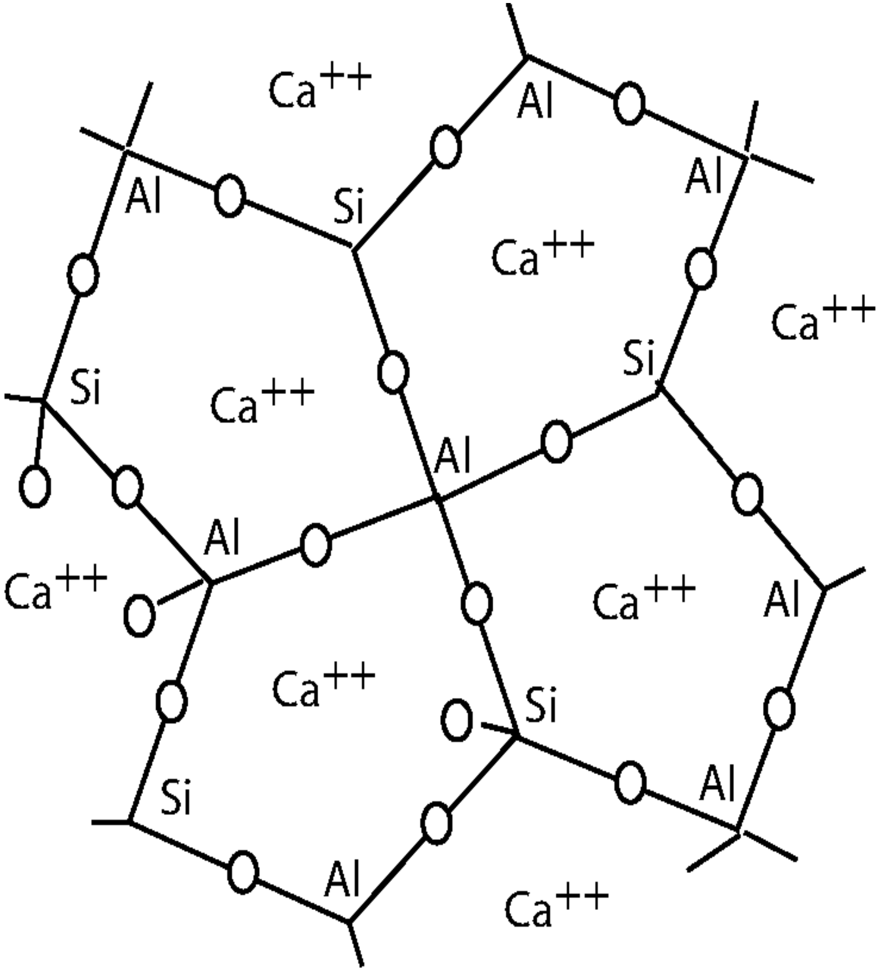
5. Reticulation, networking

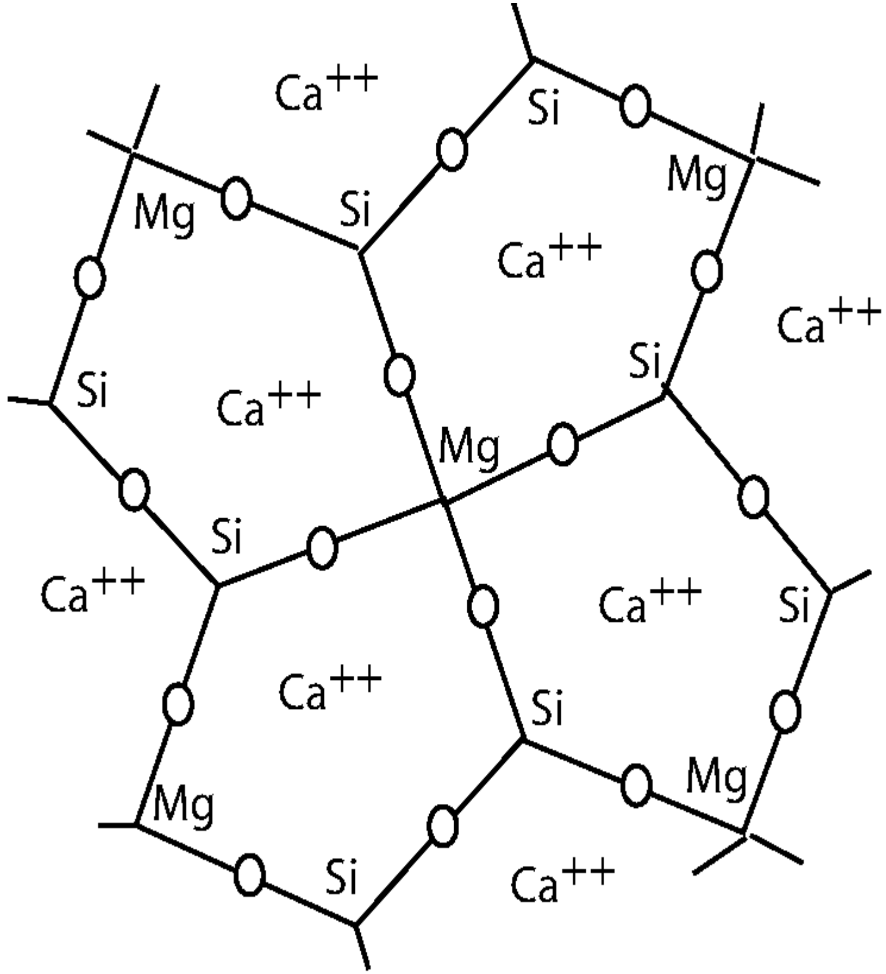
6. Geopolymer solidification

Blast furnace slag



gehlenite

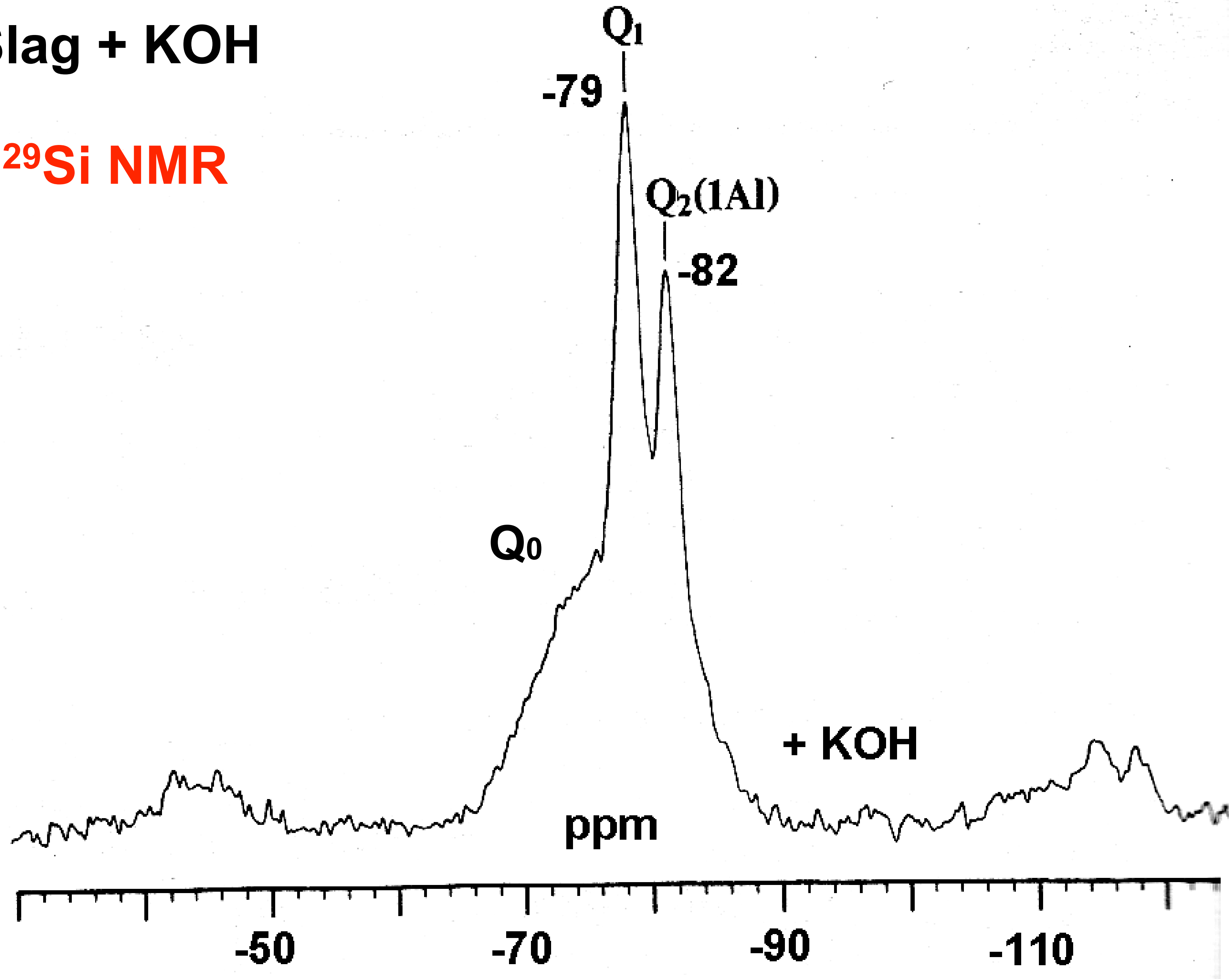
melilite



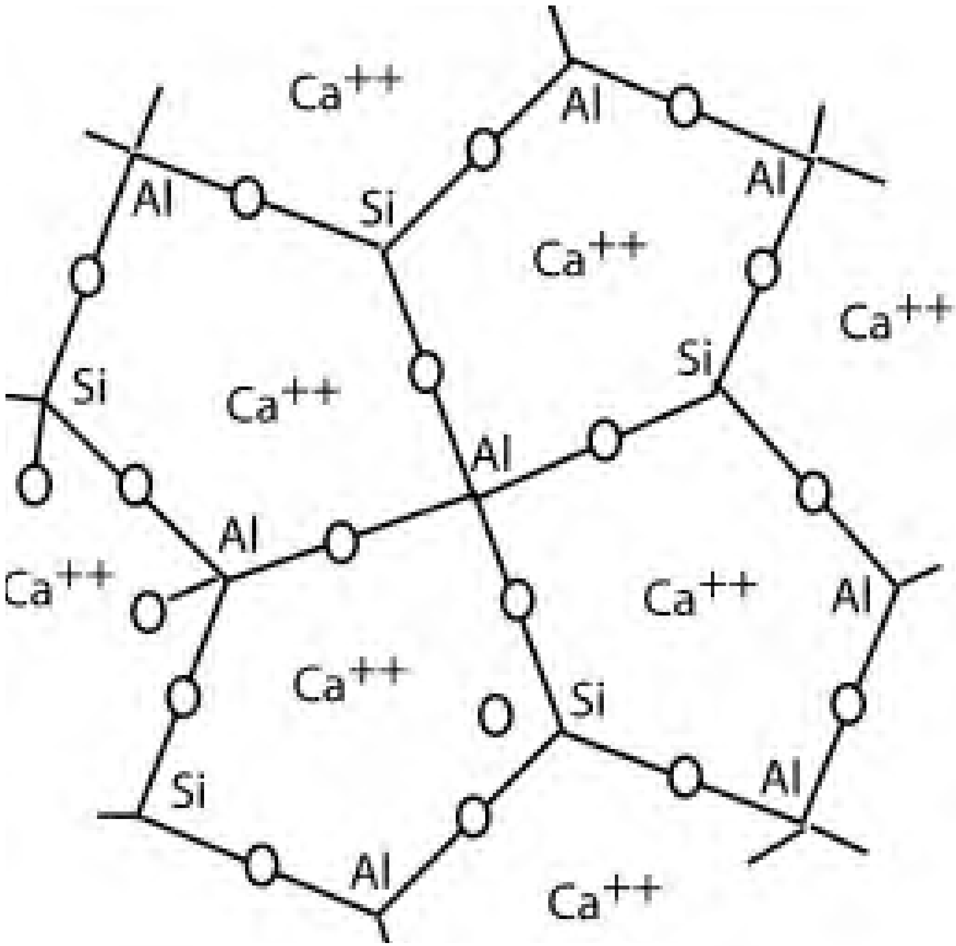
akermanite

Slag + KOH

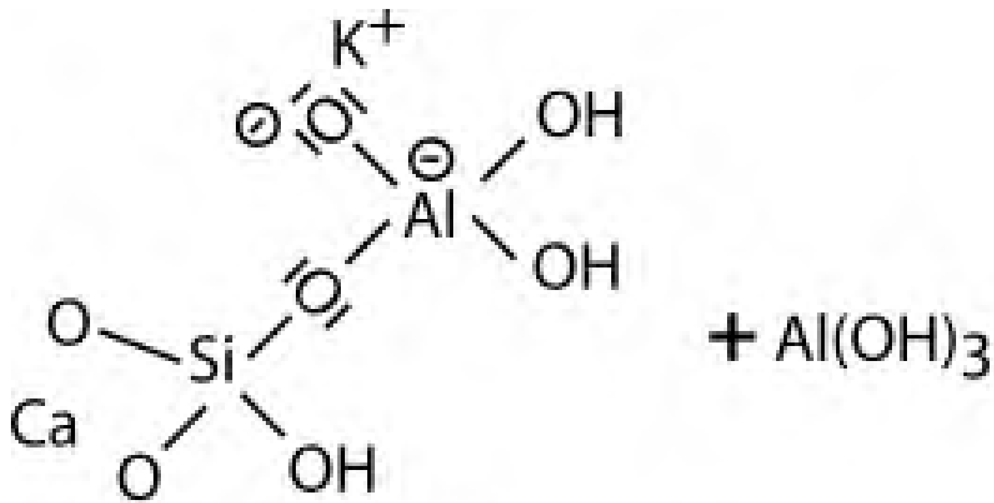
^{29}Si NMR



Alkalination

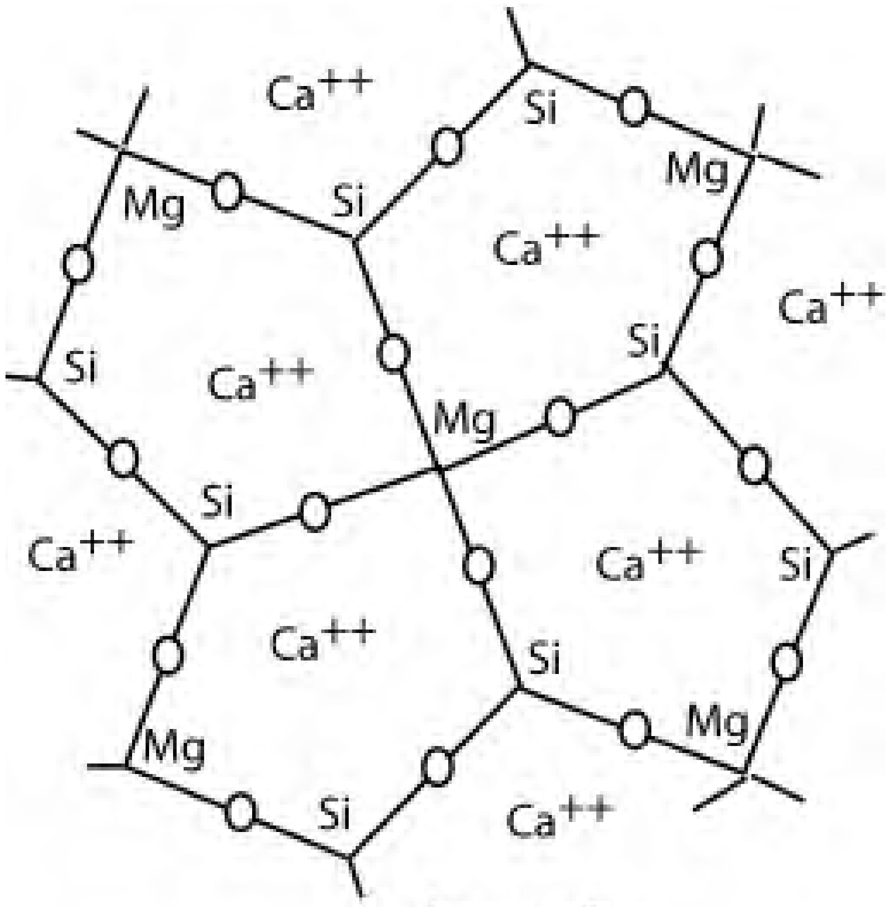


gehlenite

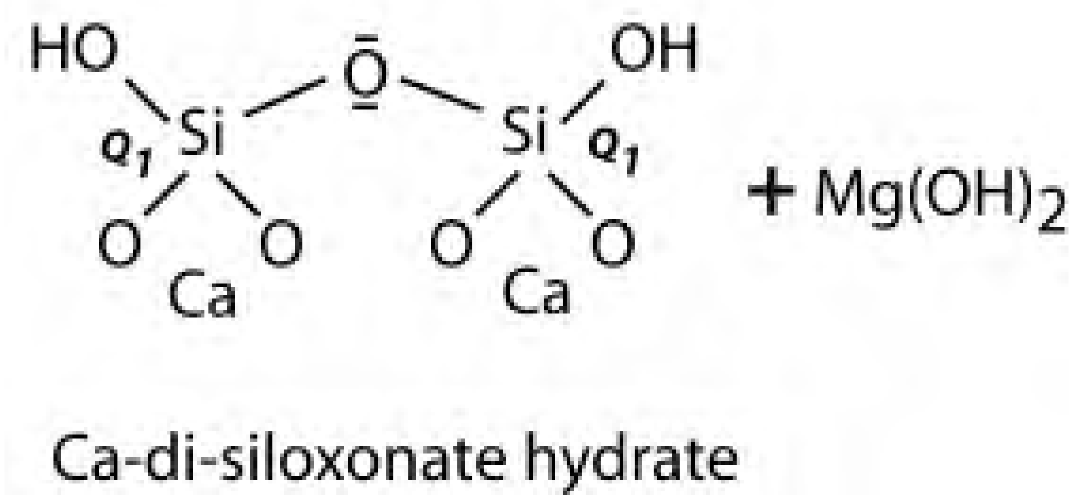


(K,Ca)-ortho-sialate hydrate

Alkalination

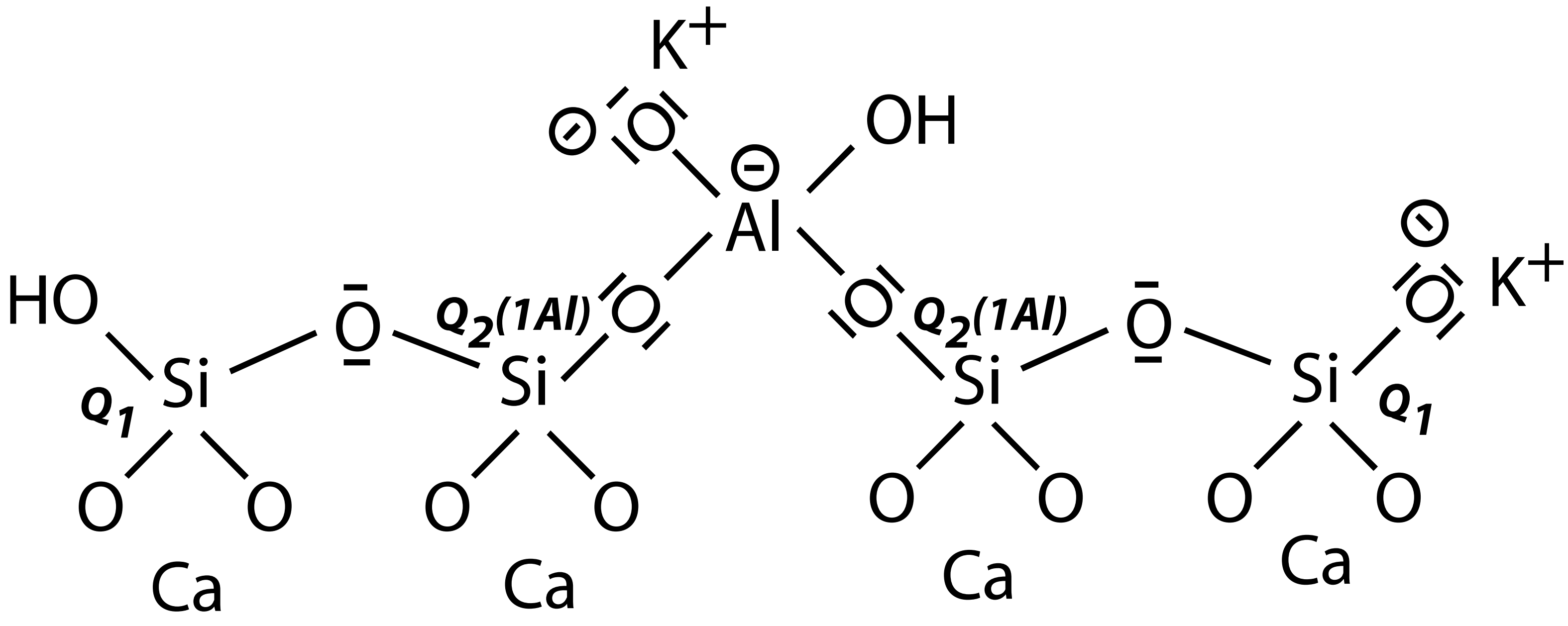


akermanite



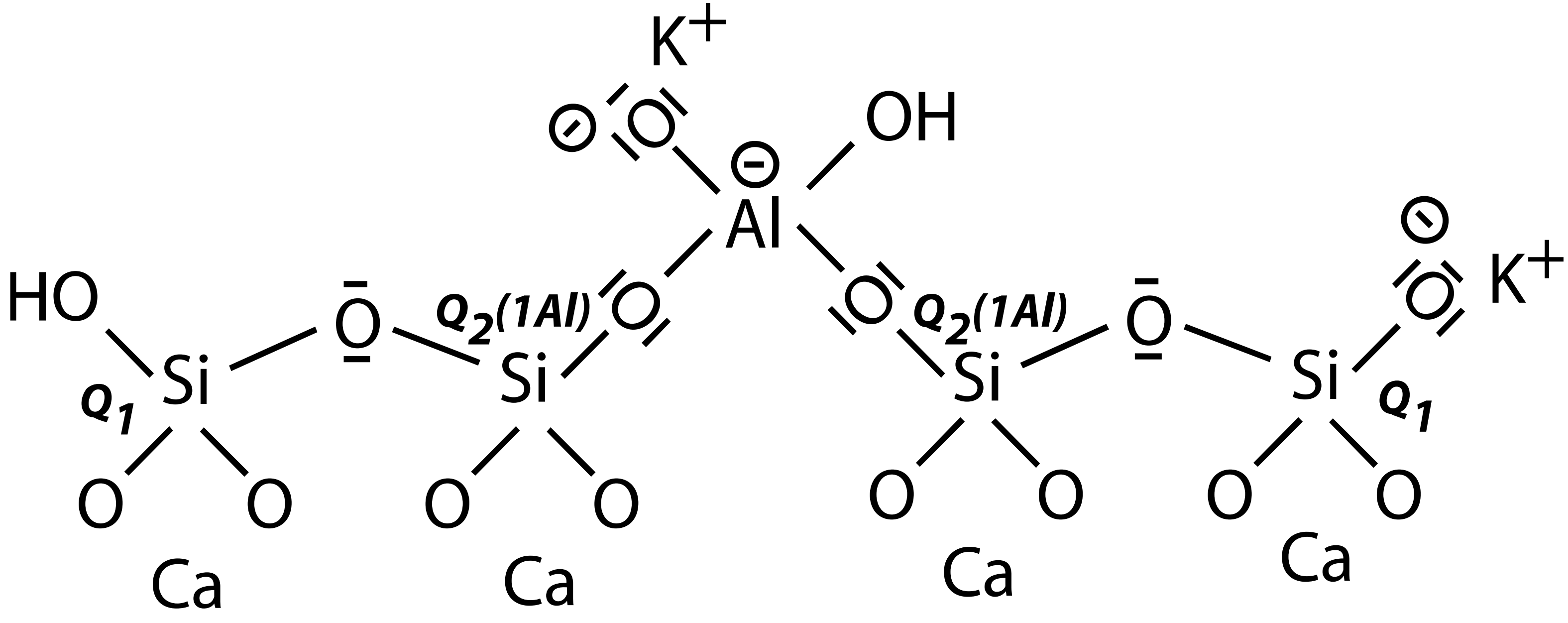
CSH

Si Q2 unit



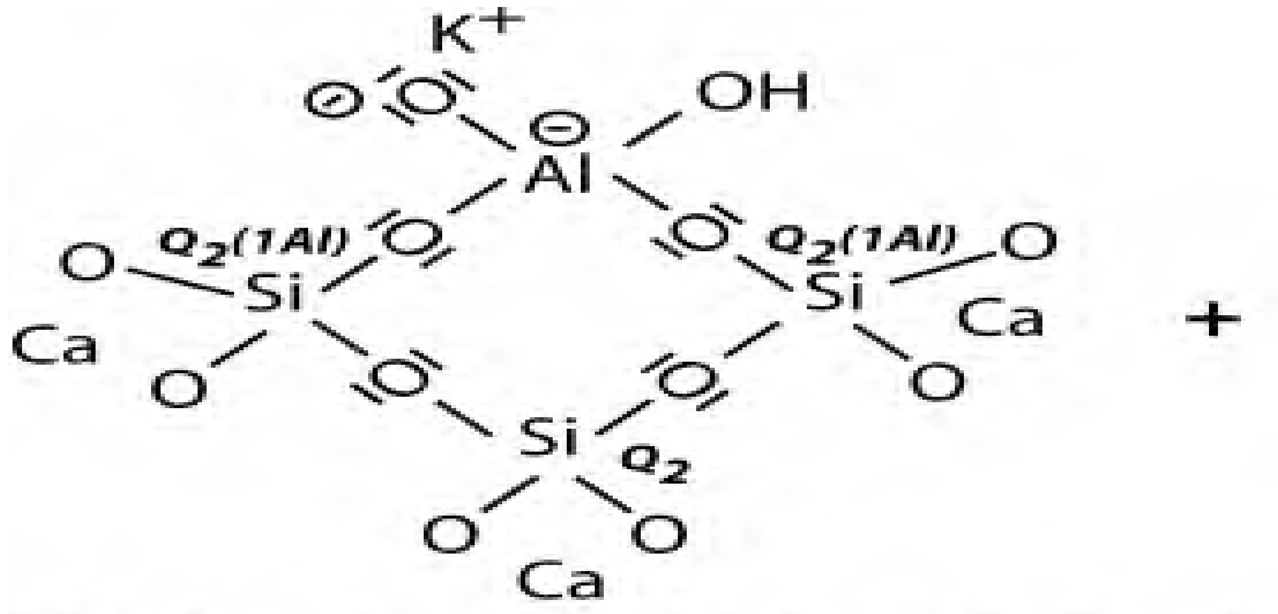
tobermorite with Al substitution

Si Q2 unit



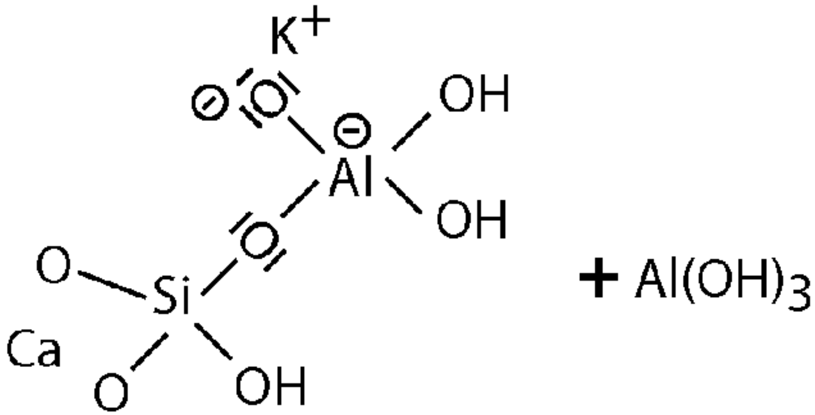
tobermorite with Al substitution

Si Q2 unit



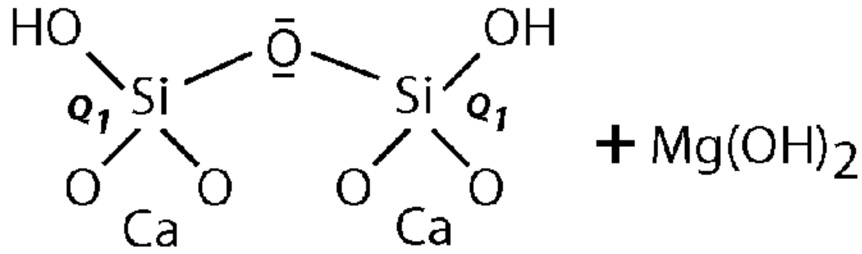
(K,Ca)-cyclo-ortho(sialate-disiloxo)

gehlenite



(K,Ca)-ortho-sialate hydrate

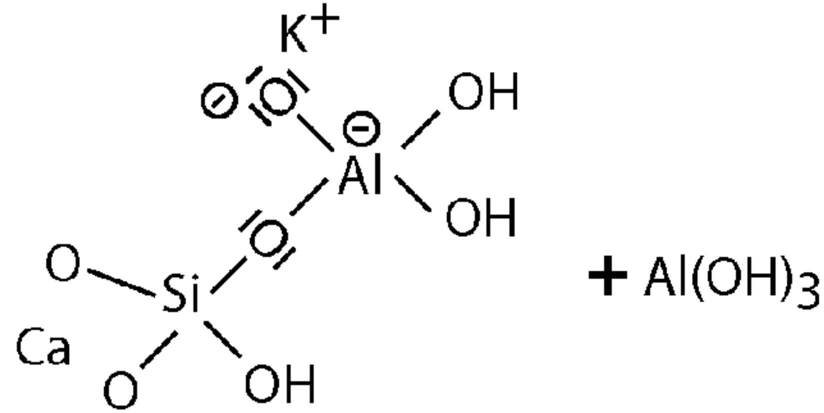
akermanite



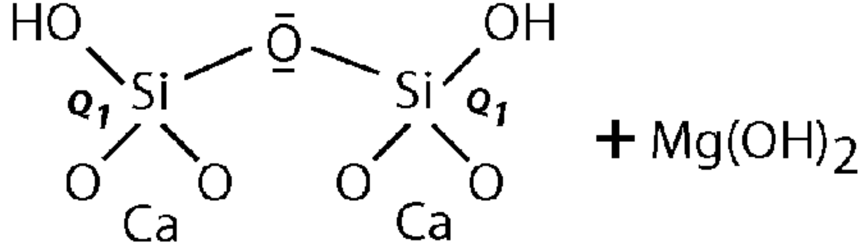
Ca-di-siloxonate hydrate

gehlenite

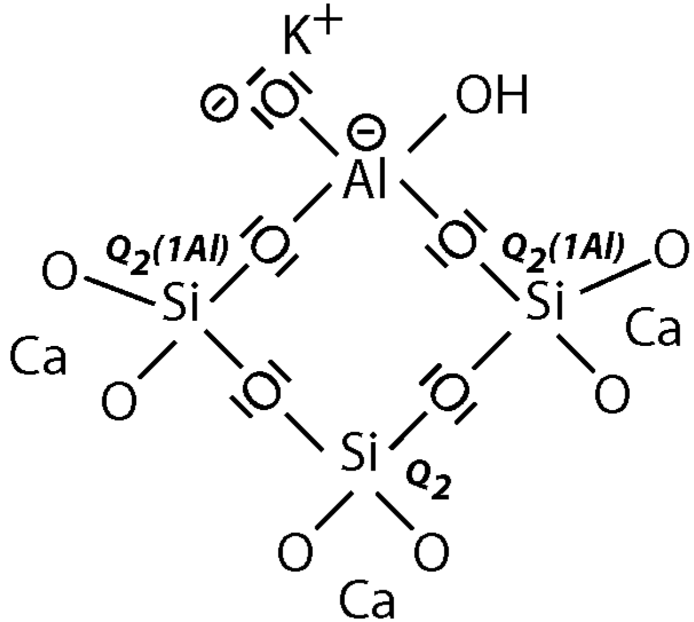
akermanite



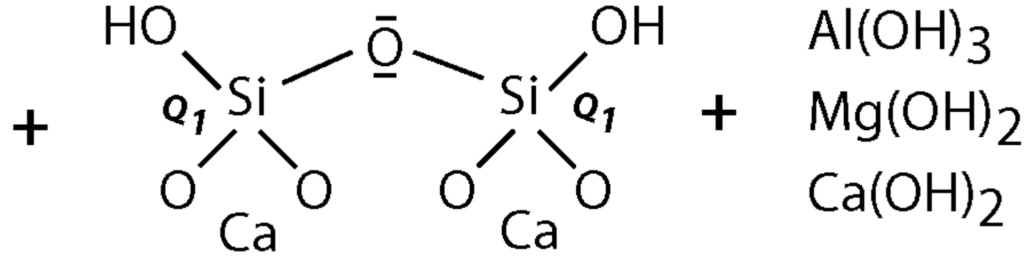
(K,Ca)-ortho-sialate hydrate



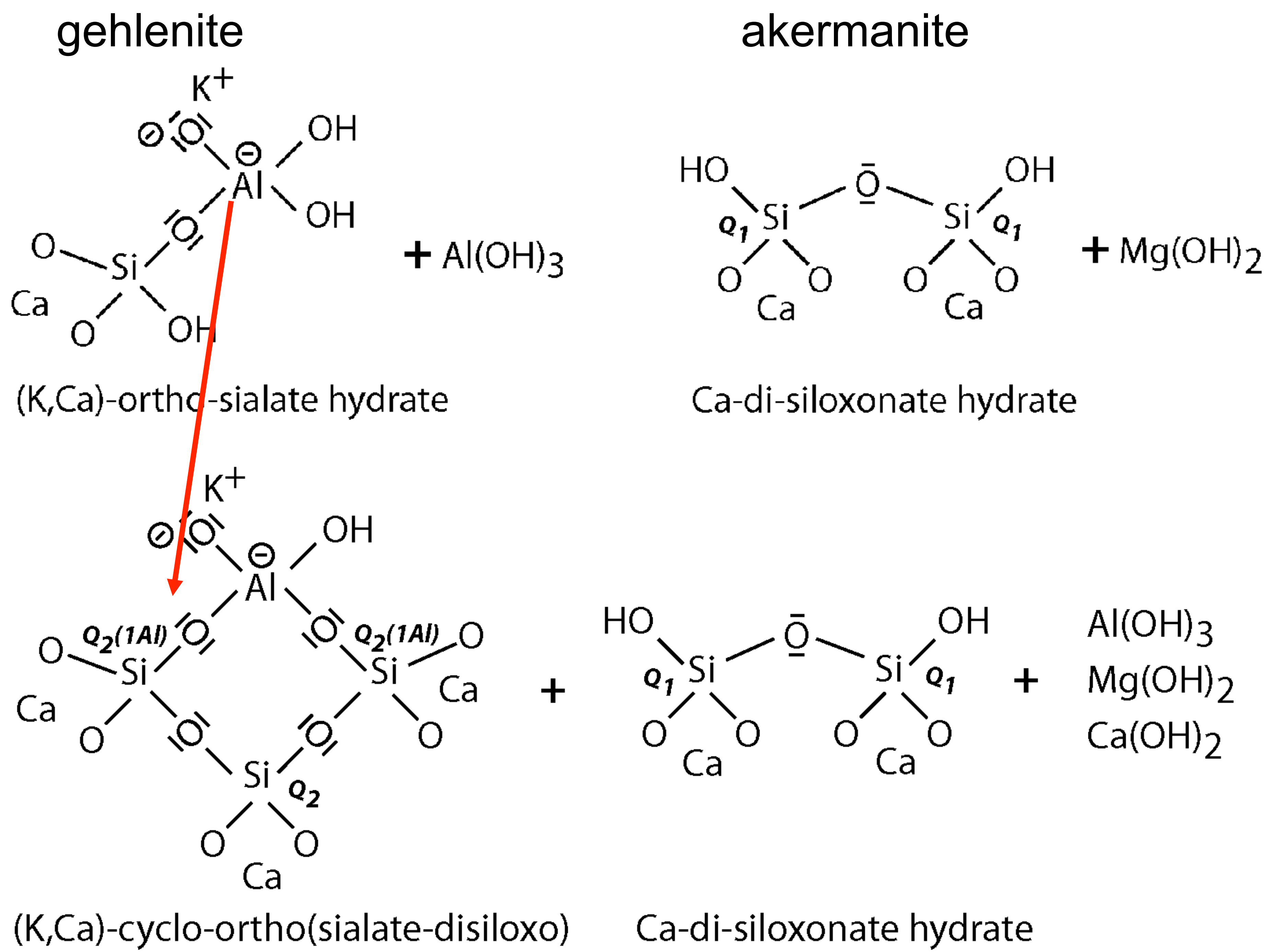
Ca-di-siloxonate hydrate



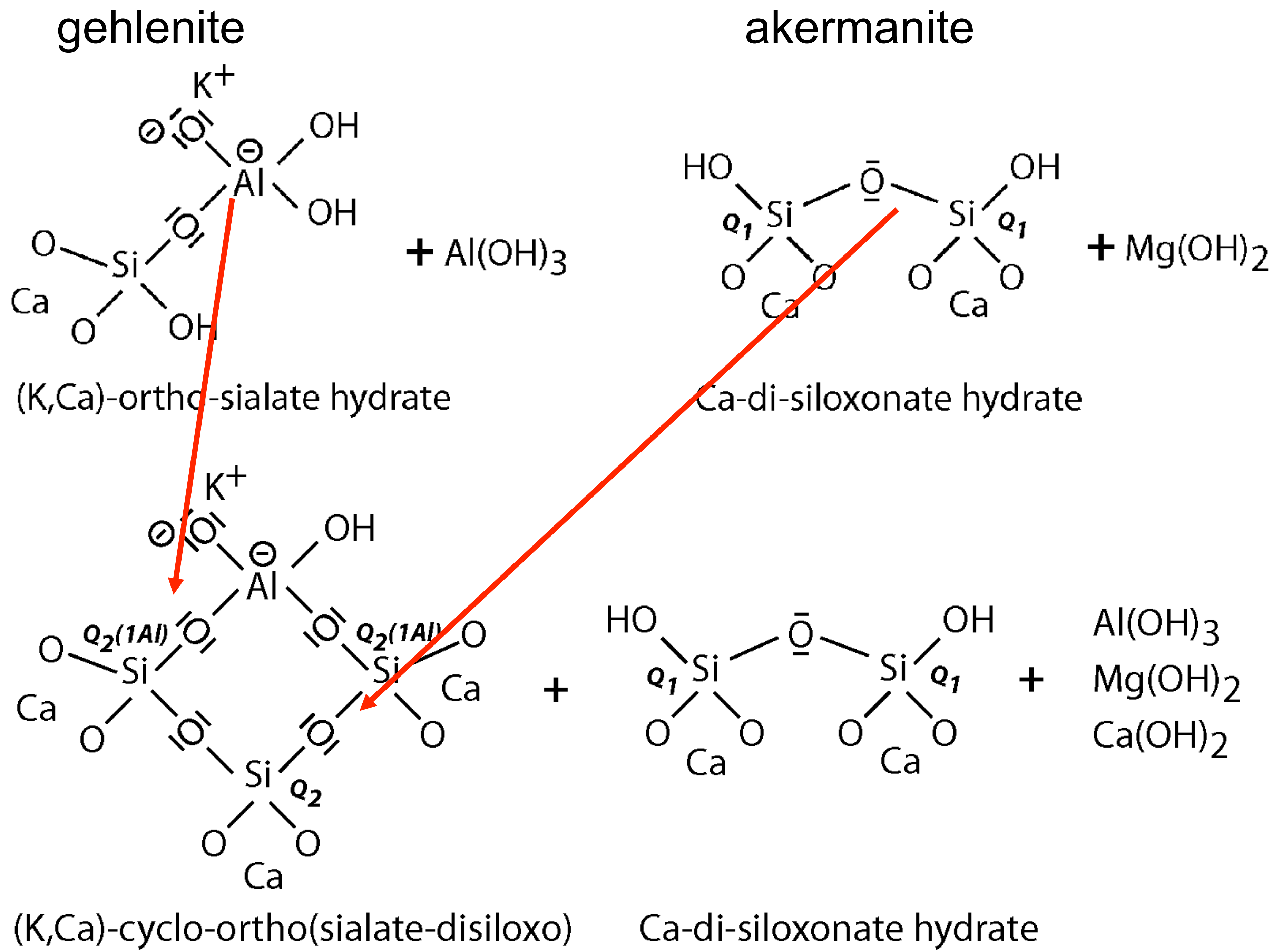
(K,Ca)-cyclo-ortho(sialate-disiloxo)



Ca-di-siloxonate hydrate



gehlenite
akermanite
K+
OH
Al
OH
O
Si
Ca
O
OH
+ Al(OH)3
(K,Ca)-ortho-sialate hydrate
HO
OH
Q1
Si
Si
Q1
O
O
O
O
Ca
Ca
+ Mg(OH)2
Ca-di-siloxonate hydrate
Q2(1Al)
Q2(1Al)
Q2
+
+
Al(OH)3
Mg(OH)2
Ca(OH)2
(K,Ca)-cyclo-ortho(sialate-disiloxo)
Ca-di-siloxonate hydrate


gehlenite
akermanite
K+
OH
Al
OH
O
Si
Ca
O
OH
+ Al(OH)3
HO
O
OH
Q1
Si
Si
Q1
O
O
O
O
Ca
Ca
+ Mg(OH)2
(K,Ca)-ortho-sialate hydrate
Ca-di-siloxonate hydrate
K+
OH
Al
Q2(1Al)
Q2(1Al)
O
O
Si
Si
Ca
Ca
O
O
Si
Q2
O
O
Ca
+
HO
O
OH
Q1
Si
Si
Q1
O
O
O
O
Ca
Ca
+
Al(OH)3
Mg(OH)2
Ca(OH)2
(K,Ca)-cyclo-ortho(sialate-disiloxo)
Ca-di-siloxonate hydrate

1) MK-750 / slag - based

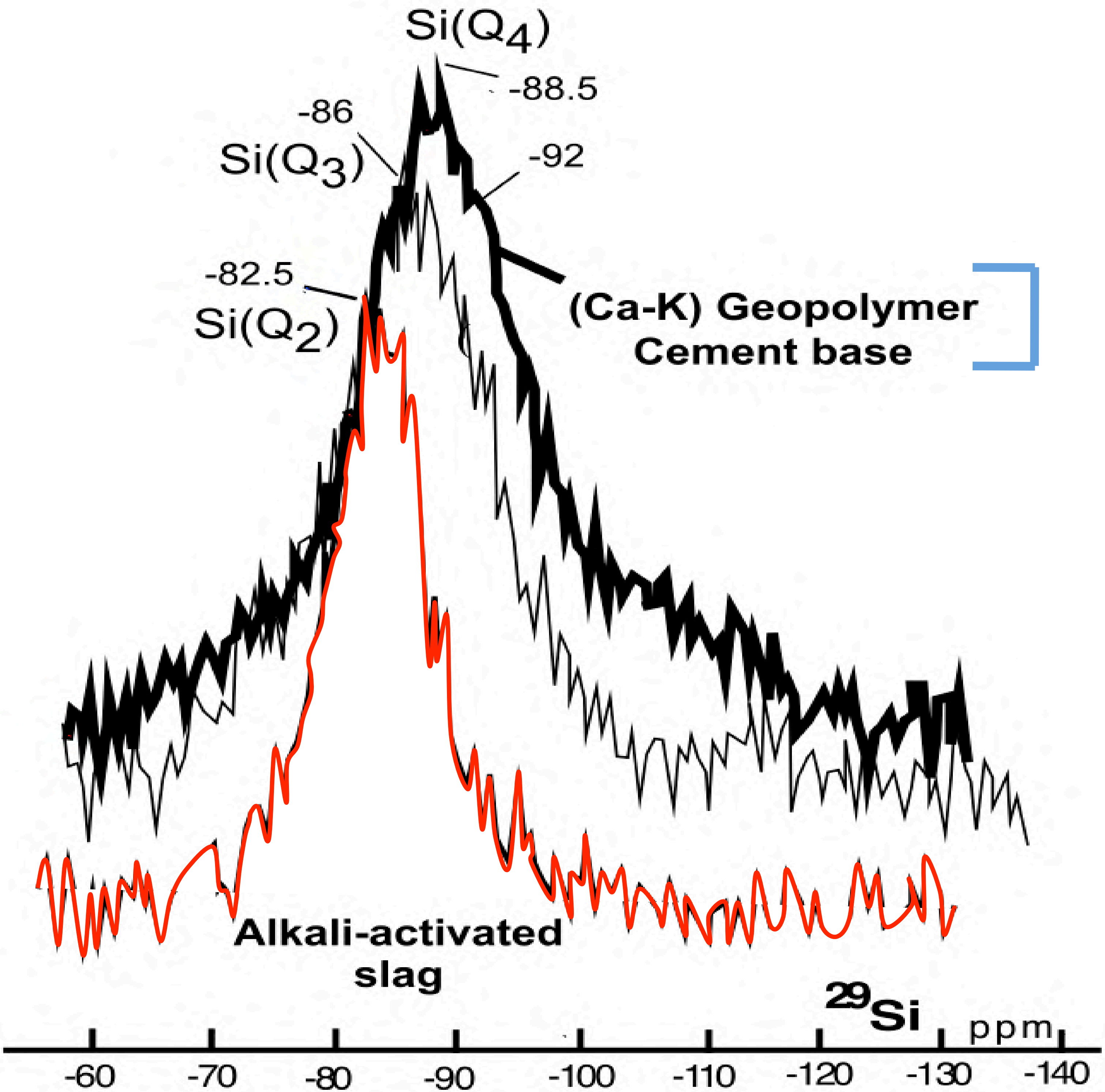
2) Rock / slag-based

3) Fly ash / slag-based

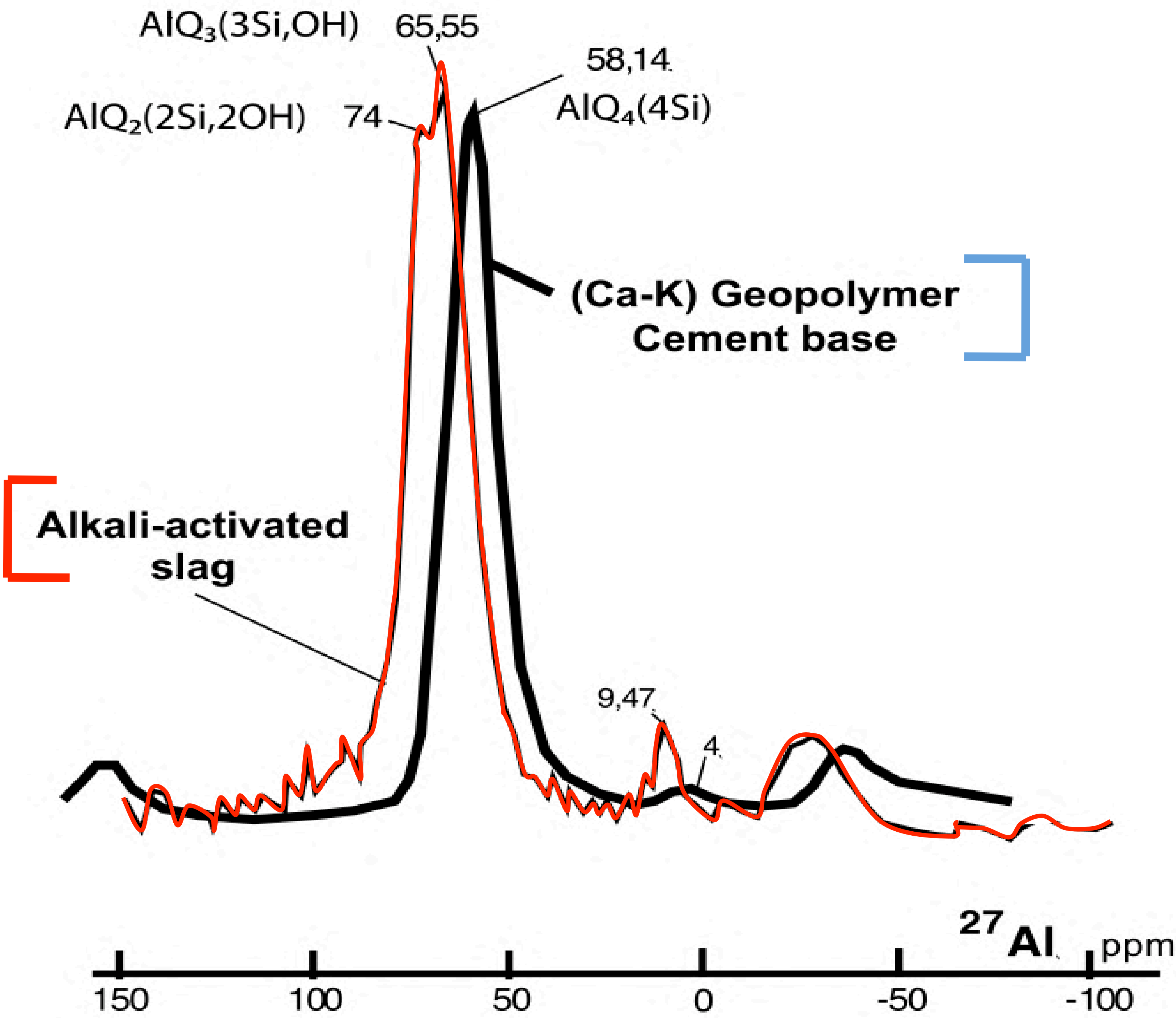
(1)

Geopolymerization

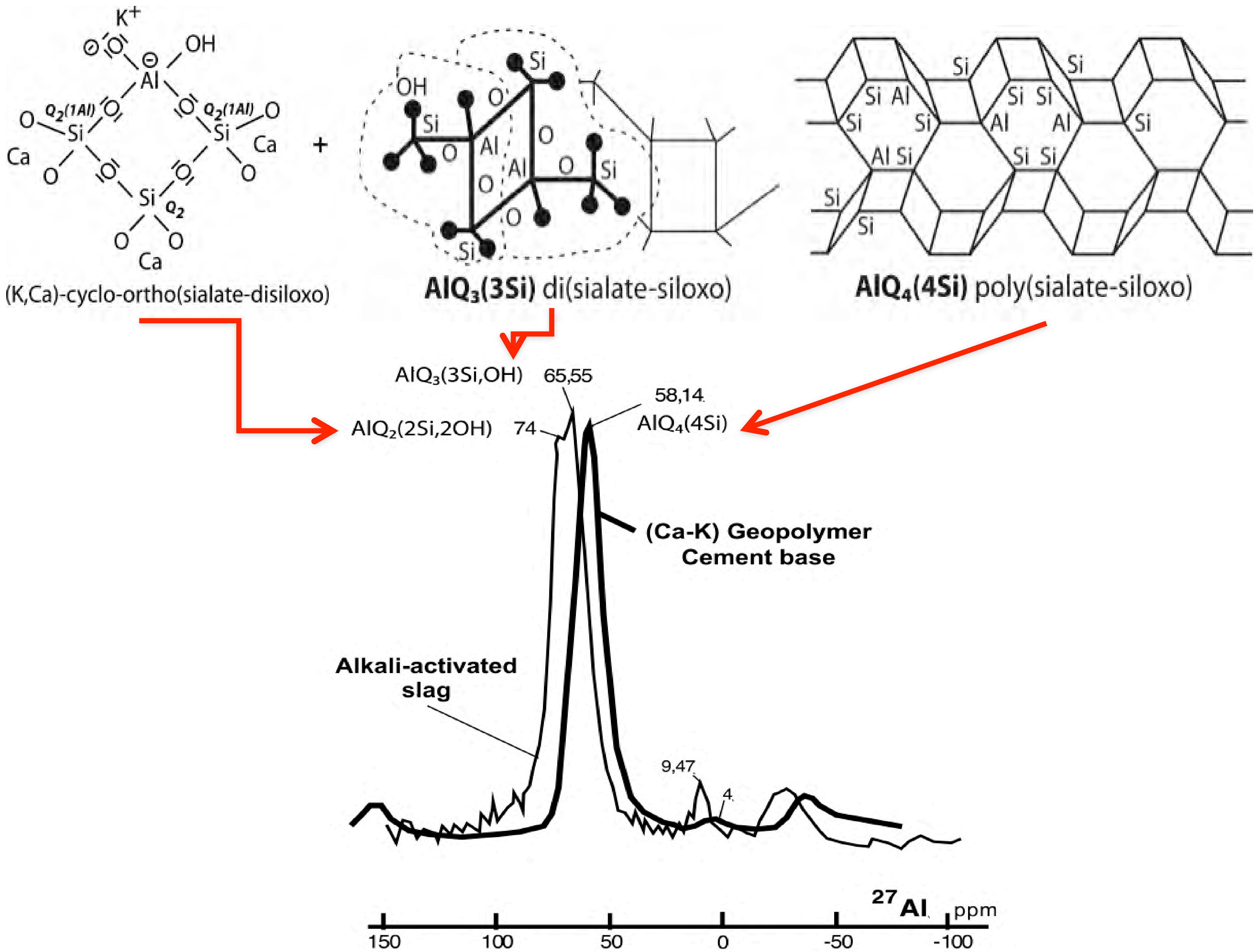
MK-750 + slag



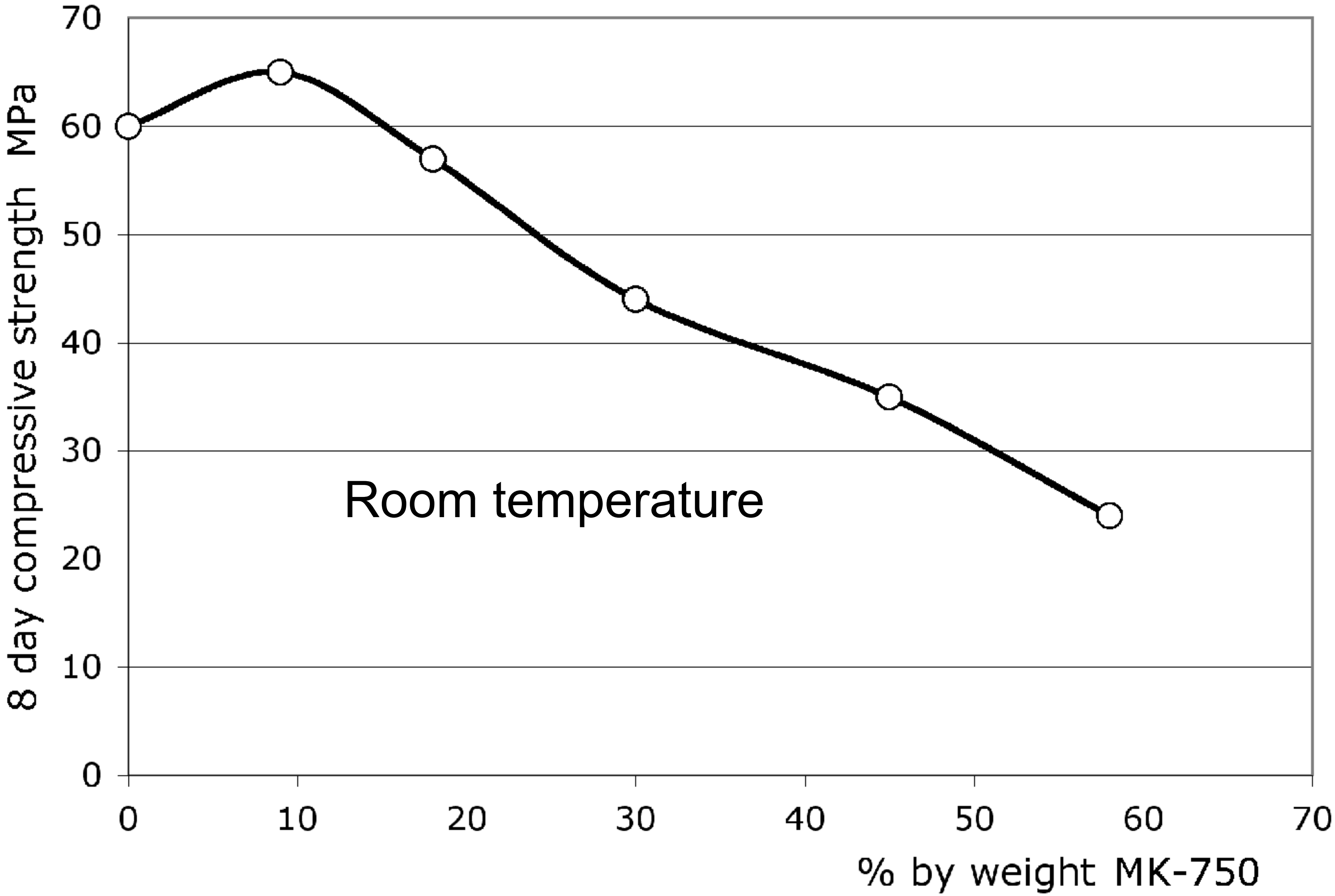
Si(Q4)
-88.5
-86
Si(Q3)
-92
-82.5
Si(Q2)
(Ca-K) Geopolymer
Cement base
Alkali-activated
slag
29Si
ppm
-60
-70
-80
-90
-100
-110
-120
-130
-140



AlQ3(3Si,OH)
65,55
58,14
AlQ2(2Si,2OH)
74
AlQ4(4Si)
(Ca-K) Geopolymer
Cement base
Alkali-activated
slag
9,47
4
27Al
ppm
150
100
50
0
-50
-100


K+
OH
Al
Q2(1Al)
Si
Ca
Q2
(K,Ca)-cyclo-ortho(sialate-disiloxo)
+
AlQ3(3Si) di(sialate-siloxo)
AlQ4(4Si) poly(sialate-siloxo)
AlQ3(3Si,OH)
65,55
58,14
AlQ2(2Si,2OH)
74
AlQ4(4Si)
(Ca-K) Geopolymer
Cement base
Alkali-activated
slag
9,47
4
27Al ppm
150
100
50
0
-50
-100

8 day strength / % MK-750



The Choice

The Choice

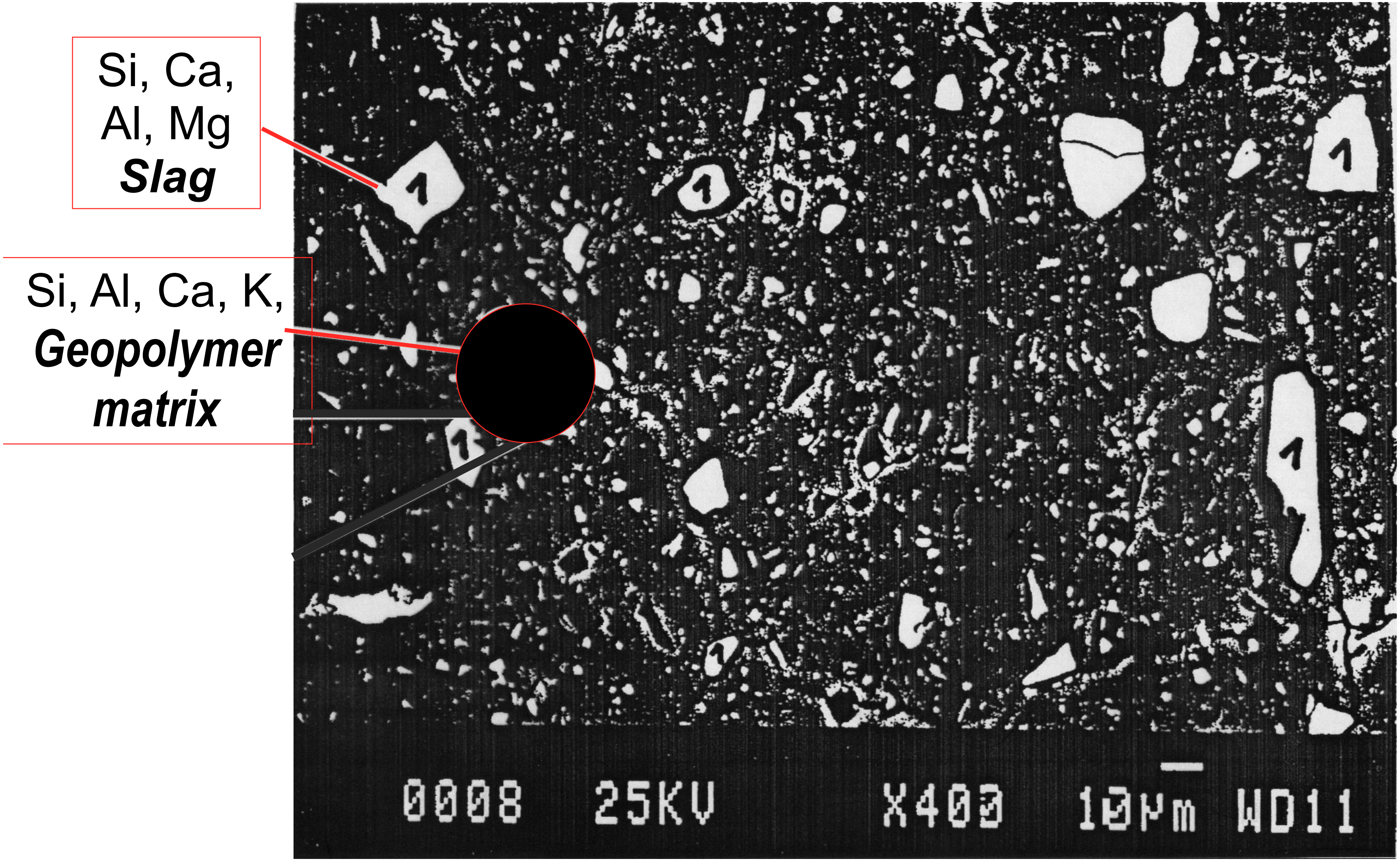
- ❑ high strength with bad physico-chemical properties

The Choice

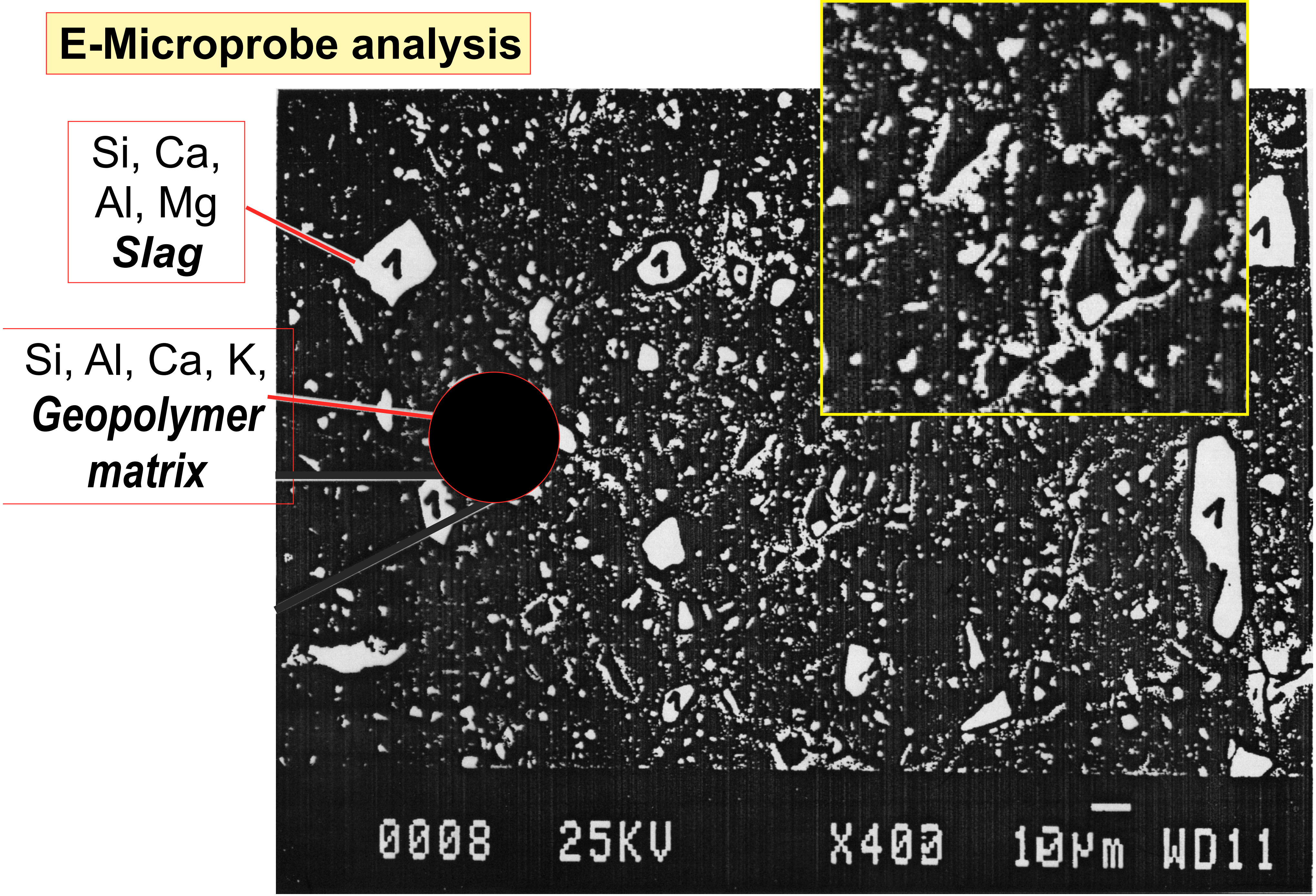
- ❑ high strength with bad physico-chemical properties
- ❑ medium strength with high durability

E-Microprobe analysis

E-Microprobe analysis



E-Microprobe analysis



atomic ratios

Si:Al	1.65	
K:Al	0.48	Si:K 3.43
Ca:Al	0.65	Si:Ca 2.53

electronic micro beam analysis

Si:Al	1.655 (1.317 to 1.832)	
K:Al	0.442 (0.192 to 0.614)	Si:K 3.73
Ca:Al	0.679 (0.388 to 0.870)	Si:Ca 2.43

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geopolymeric matrix may be a solid solution of

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geopolymeric matrix may be a solid solution of

✓ **- 1.67[K-poly(sialate)], kalsilite, hydrate**

atomic ratios

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+ 0.41[Ca-poly(di-sialate)], anorthite hydrate;

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✓ **- 0.33[K-poly(sialate-disiloxo)], orthoclase hydrate,**

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+ 0.08[Ca-poly(di-sialate)], anorthite hydrate;

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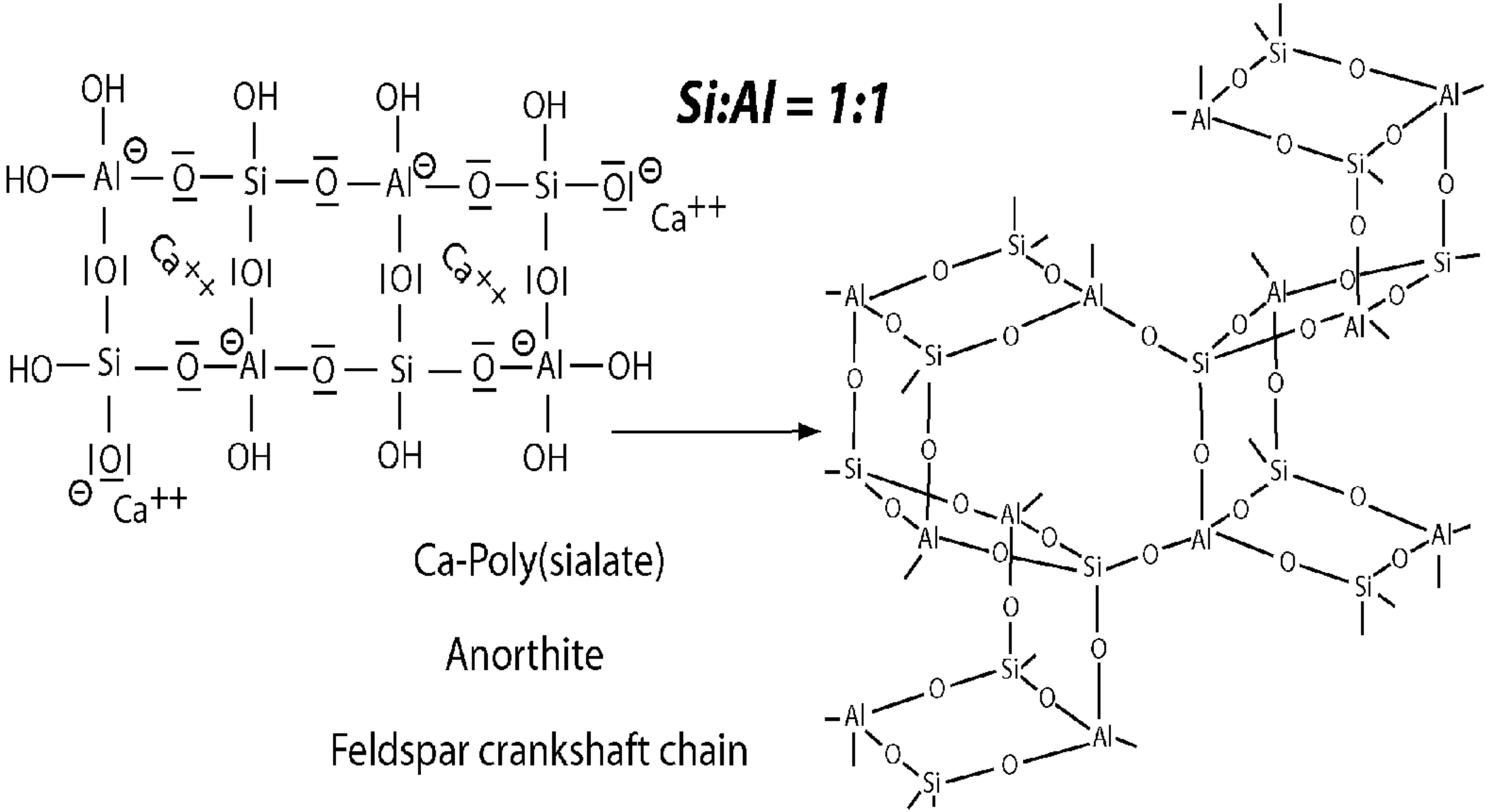
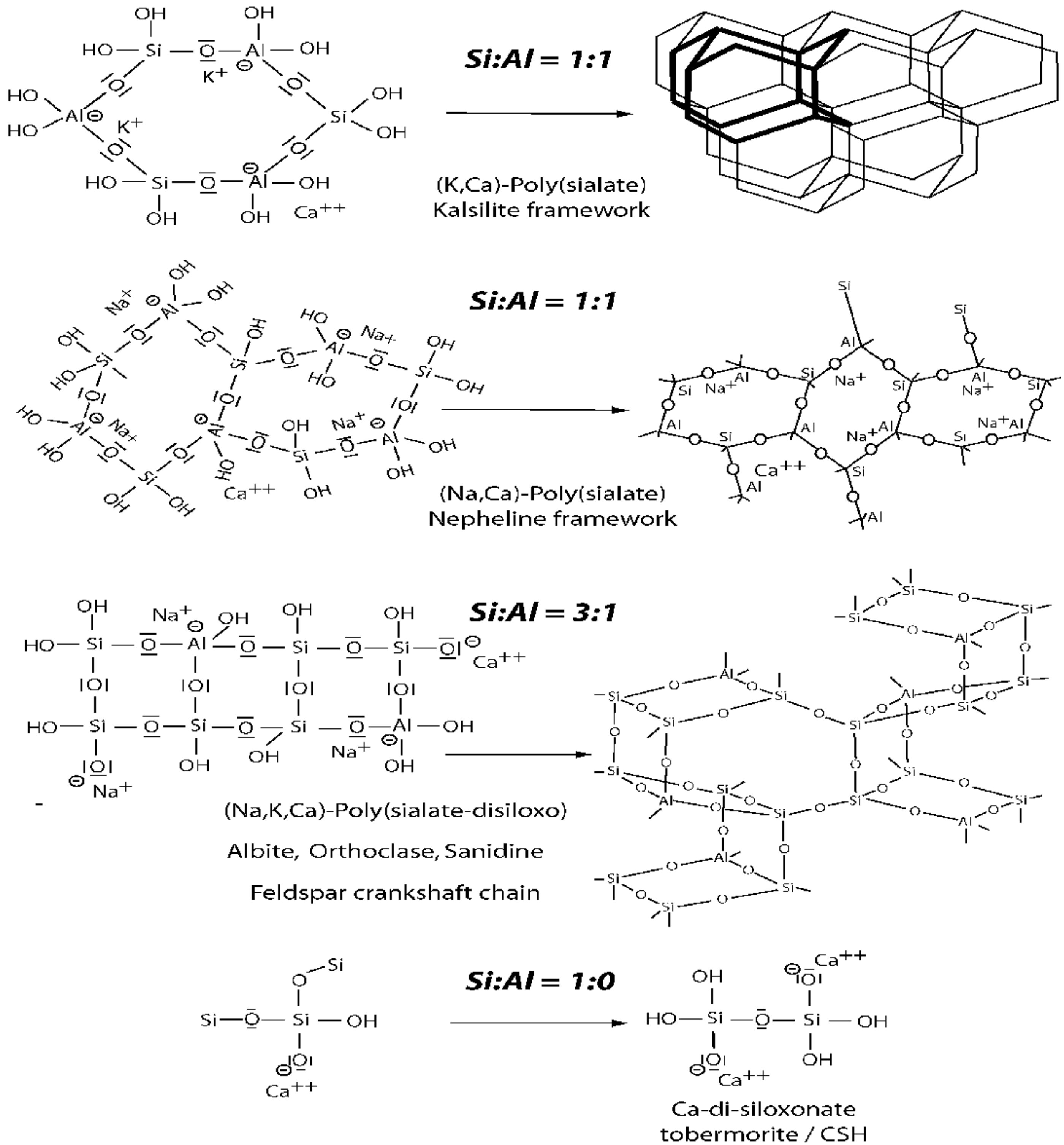
+ 0.08[Ca-poly(di-sialate)], anorthite hydrate;

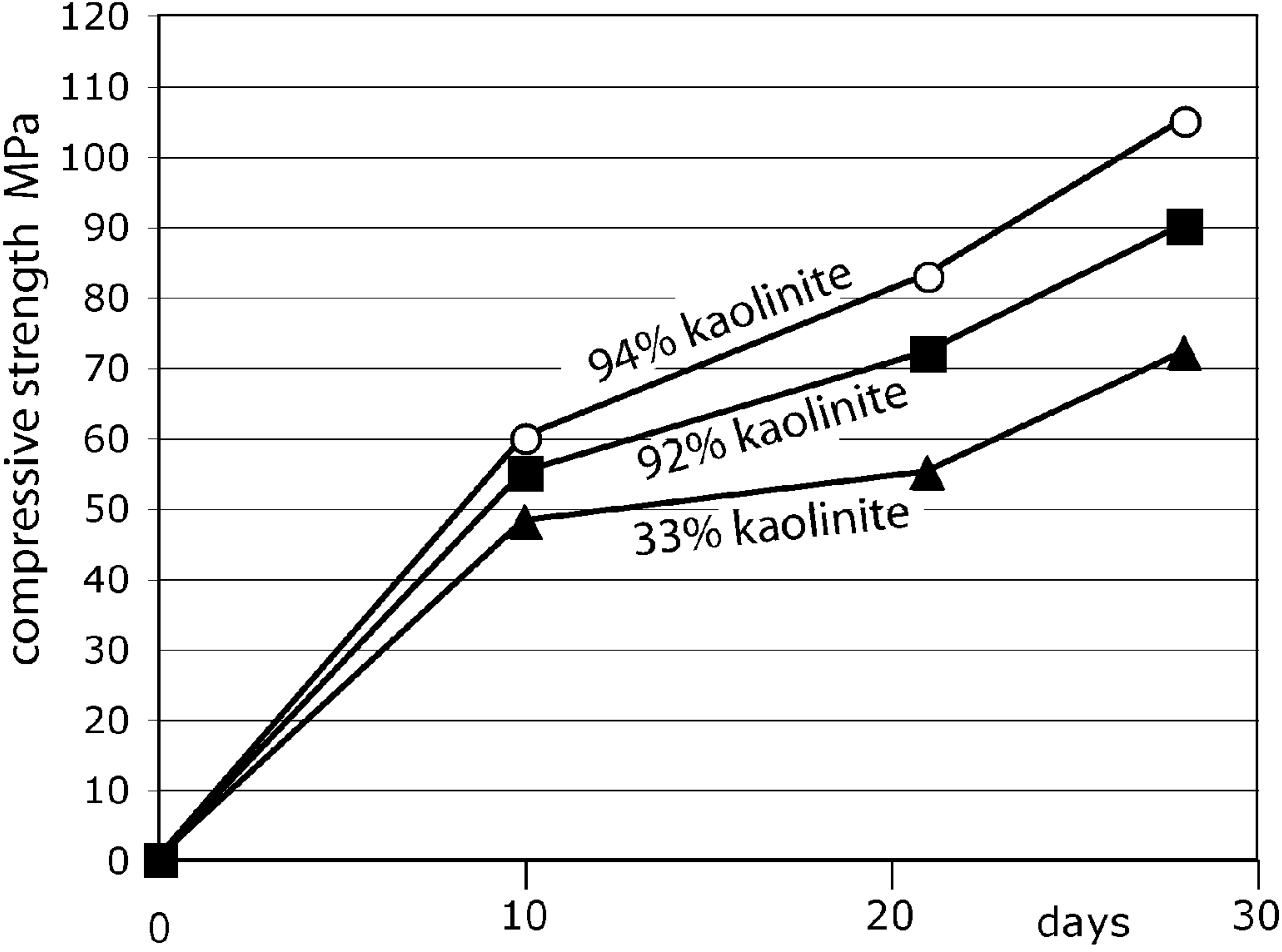
✓ **- 0.5[Ca-di-siloxonate] (CSH) + CAH …**


Si:Al = 1:1
Ca-Poly(sialate)
Anorthite
Feldspar crankshaft chain


Si:Al = 1:1
(K,Ca)-Poly(sialate)
Kalsilite framework
Si:Al = 1:1
(Na,Ca)-Poly(sialate)
Nepheline framework
Si:Al = 3:1
(Na,K,Ca)-Poly(sialate-disiloxo)
Albite, Orthoclase, Sanidine
Feldspar crankshaft chain
Si:Al = 1:0
Ca-di-siloxonate
tobermorite / CSH

MK-750 / slag-based geopolymer cement

Practical experience



compressive strength MPa
120
110
100
90
80
70
60
50
40
30
20
10
0
94% kaolinite
92% kaolinite
33% kaolinite
0
10
20
days
30

Basic MK-750/slag mix:

a) calcined kaolinitic clay………..80

b) slag (15-25 microns) …………20

c) K silicate sol.

(MR = 1,40), H_2O:53%.........20

d) water…………………………….2

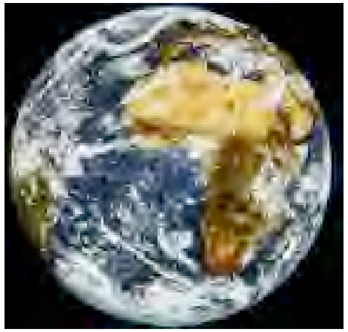
Ambient temperature hardening

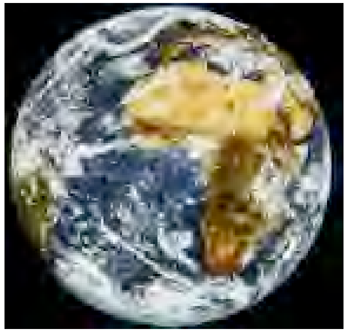
45 MPa at 7 days

70 MPa at 28 days.

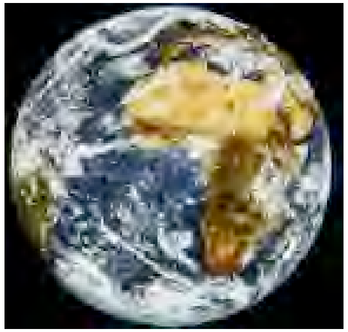
(2)

Rock / slag - based geopolymer cement



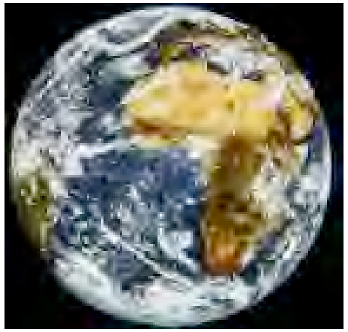


Si:Al = 3:1
Poly(sialate-disiloxo) geopolymeric cement



Si:Al = 3:1
Poly(sialate-disiloxo) geopolymeric cement

Based on geological raw-materials



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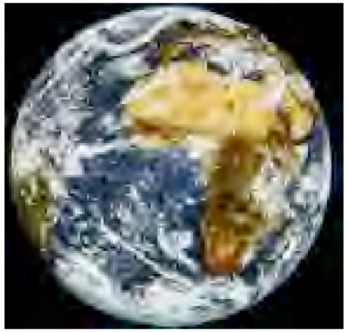
Poly(sialate-disiloxo) geopolymeric cement

Based on geological raw-materials

Compressive Strength at 28 days (room temperature hardening) :



Si:Al = 3:1
Poly(sialate-disiloxo) geopolymeric cement

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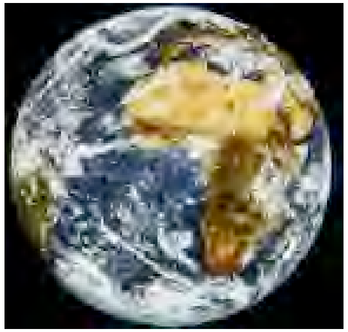
Compressive Strength at 28 days (room temperature hardening) :

✦ **European raw materials: up to 140 MPa**

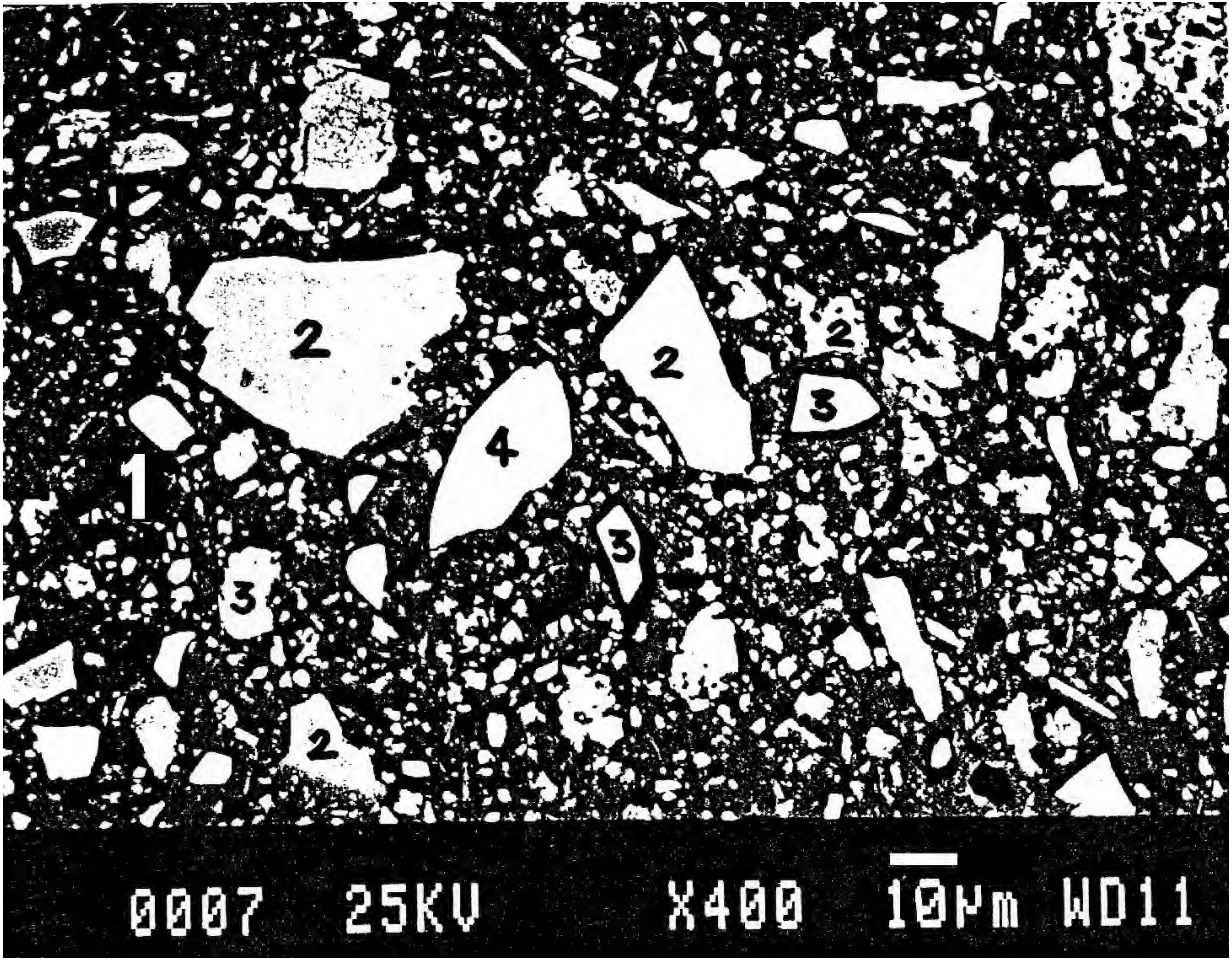


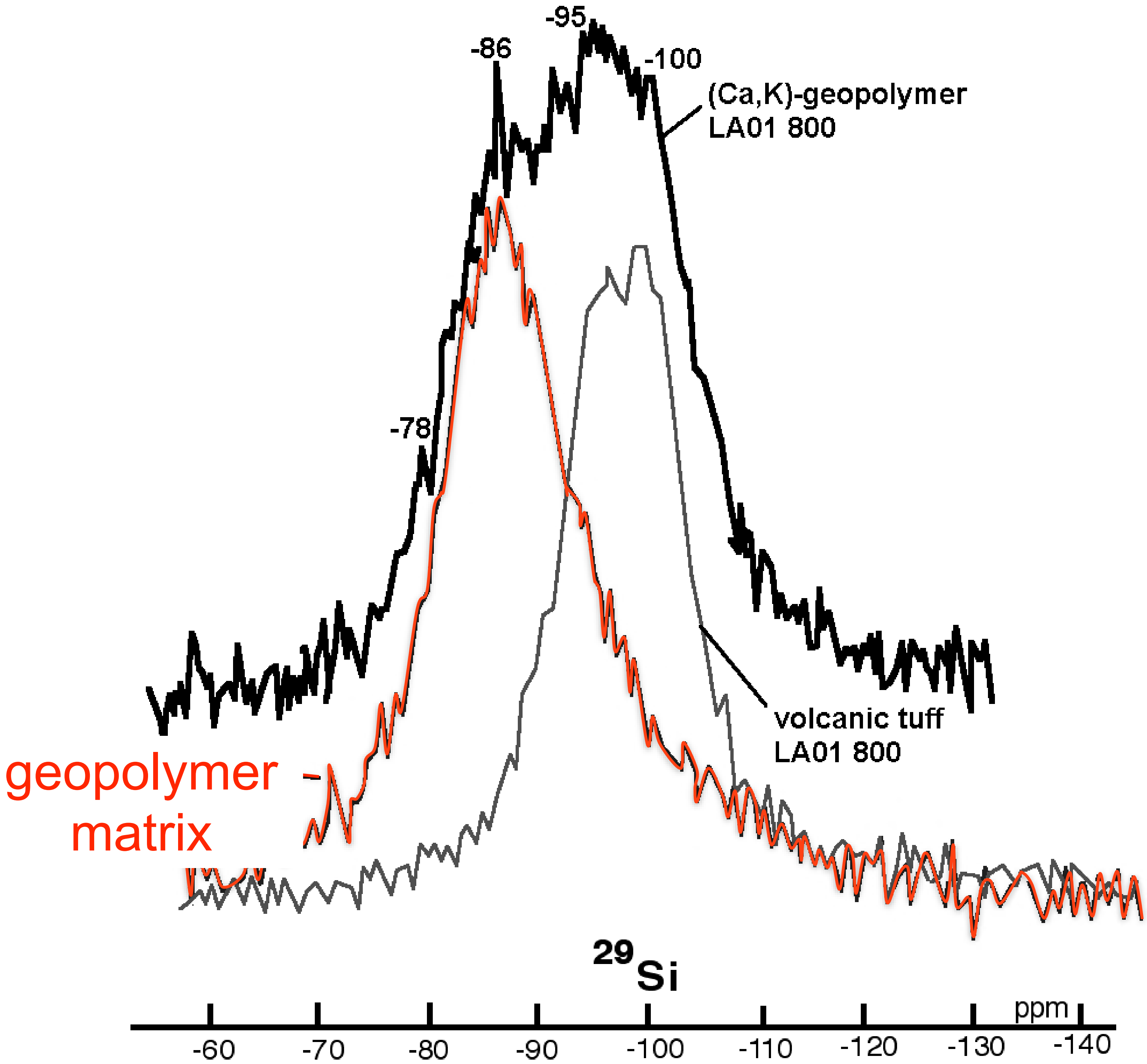
Si:Al = 3:1
Poly(sialate-disiloxo) geopolymeric cement

Based on geological raw-materials

Compressive Strength at 28 days (room temperature hardening) :

- ✦ **European raw materials:** **up to 140 MPa**
- ✦ **Qatari raw materials:** **up to 150 MPa**


1
2
2
2
2
3
3
3
4
0007 25KV X400 10μm WD11



-95
-86
-100
(Ca,K)-geopolymer
LA01 800
-78
volcanic tuff
LA01 800
geopolymer
matrix
29Si
ppm
-60
-70
-80
-90
-100
-110
-120
-130
-140

Coal-waste tailing

Coal-waste tailing

- 25% plagioclase (feldspar),
- 30% quartz,
- 10% amphibole,
- 27% kaolinite,
- 3-5% coal and
- 6% of other elements.

Coal-waste tailing

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- 10% amphibole,
- 27% kaolinite,
- 3-5% coal and
- 6% of other elements.

calcined at 750°C for 3 hours,

ground to 15-25 microns.

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- 30% quartz,
- 10% amphibole,
- 27% kaolinite,
- 3-5% coal and
- 6% of other elements.

calcined at 750°C for 3 hours,

ground to 15-25 microns.

Remains of coal supply part of needed energy

Coal-waste tailing mixture:

a) coal-mining waste …………….80

b) slag (15-25 microns) …………20

c) K silicate sol.

(MR = 1,40), H_2O:53%.........20

d) water……………………………20

Ambient temperature hardening

30 MPa at 7 days

75 MPa at 28 days.

Special coal-mining tailings

Coal-waste tailing, calcined by Nature

Coal-waste tailing, calcined by Nature

batiweb
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Sept. 2010

DÉVELOPPEMENT DURABLE DU BÂTIMENT

Publié le 30 septembre 2010

LAFARGE ÉLABORE UN CIMENT À EMPREINTE DE CO^2 FORTEMENT RÉDUITE

Ce nouveau produit, un clinker, qui sert à fabriquer le ciment, entrant lui-même dans la liste des constituants du béton, a un taux réduit d'environ 30% de calcaire. Grâce à une augmentation de Gypse, argile ou bouxite, les chercheurs de Lafarge affirment que la réduction des émissions de CO^2 atteint 25%. De plus, en réduisant la

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Patent filed in 2004, granted and issued in 2010; pilot plant funding through European Union

At the Geopolymer Camp 2010

At the Geopolymer Camp 2010

GEOPOLYMER BASED CONCRETES : ENVIRONMENTAL IMPACTS OF CURRENT RESEARCH TRENDS

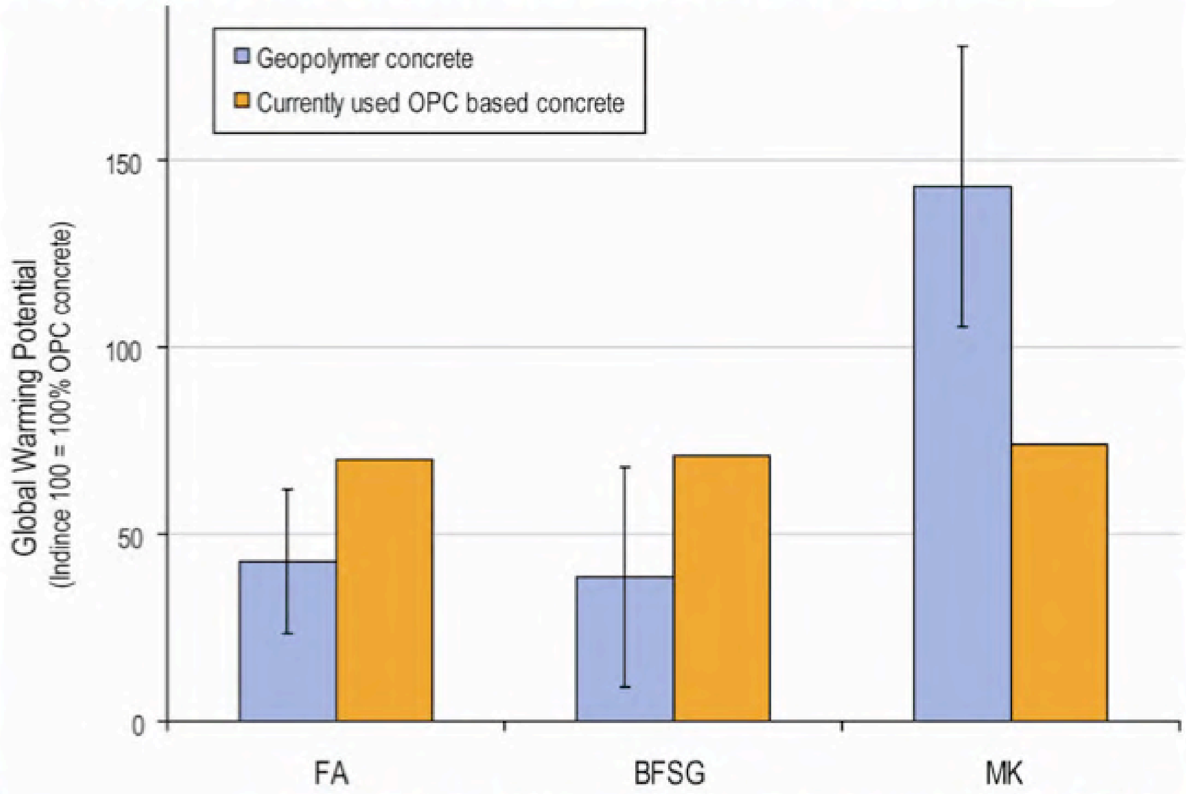
G. Habert (LCPC, Paris)
J.B. d'Espinose (ESPCI, Paris)
N. Roussel (LCPC, Paris)

LCPC Laboratoire Central des Ponts et Chaussées

Laboratoire Central des Ponts et Chaussées

Results: different geopolymer types

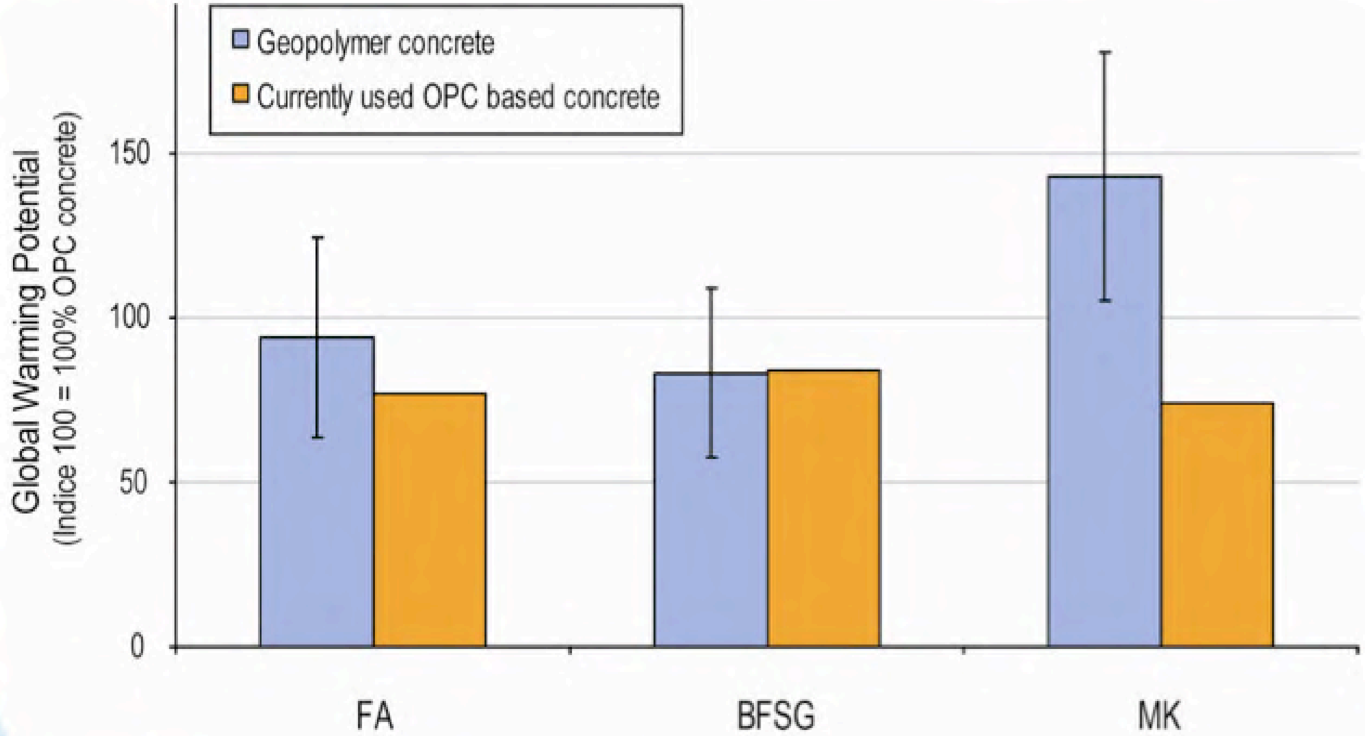
- **Concretes made with:** Fly ash, Blast furnace slag or metakaolin
  - **No allocation (waste)**



Mean FA based geopolymer has 25% improvement than currently used concrete

Results: different geopolymer types

- **Concretes made with:** Fly ash, Blast furnace slag or metakaolin
  - **Economic allocation (by-product)**



No sensitive improvement of using geopolymer compared to currently used cement

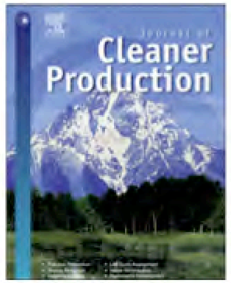
Journal of Cleaner Production 19 (2011) 1229–1238

July 2011

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro



An environmental evaluation of geopolymer based concrete production: reviewing current research trends

G. Habert [a,*], J.B. d'Espinose de Lacaillerie [b], N. Roussel [a]

[a] *Université Paris-Est, IFSTTAR, Département Matériaux, 58 bd Lefebvre, 75732 Paris cedex 15, France*
[b] *Ecole Supérieure de Physique et Chimie Industrielles, PPMD SIMM, UMR 7615 ESPCI-CNRS-UPMC, 10 rue Vauquelin, 75231 Paris cedex 05, France*

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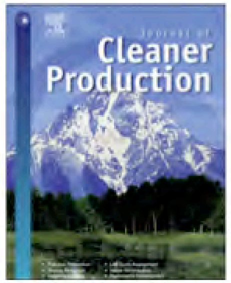

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[a] *Université Pari* … *rance*
[b] *Ecole Supérieu* … *MC, 10 rue Vauquelin, 75231 Paris cedex 05, France*

Université de Paris-Est, IFSTTAR

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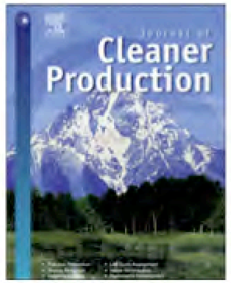

An environmental evaluation of geopolymer based concrete production: reviewing current research trends

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[b] Ecole Supérieu… MC, 10 rue Vauquelin, 75231 Paris cedex 05, France

Université de Paris-Est, IFSTTAR

« …… However, when the **production** of fly ashes and granulated blast furnace slags is taken into account,…. it appears that geopolymer concrete has a similar impact on global warming than standard concrete. »

« This study highlights that future research and development on geopolymer concrete should focus on two potential solutions:

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- 1) the use of industrial waste that is not recyclable within other industries (?????)

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- 1) the use of industrial waste that is not recyclable within other industries (?????)

-2) on the production of geopolymer concrete using a mix of blast furnace slag and activated clays.

« This study highlights that future research and development on geopolymer concrete should focus on two potential solutions:

- 1) the use of industrial waste that is not recyclable within other industries (?????)

-2) on the production of geopolymer concrete using a mix of blast furnace slag and activated clays.

It is only by adopting these directions that geopolymer concrete could allow us to achieve the current objectives for a long term reduction of CO_2 emissions. »

« This study highlights that future research and development on geopolymer concrete should focus on two potential solutions:

- 1) the ... lable within other inc...

-2) on th... sing a mix of blast fur...

They are re-inventing the wheel !!

For whom? LAFARGE.

How ?

It is only by adopting these directions that geopolymer concrete could allow us to achieve the current objectives for a long term reduction of CO_2 emissions. »

Search

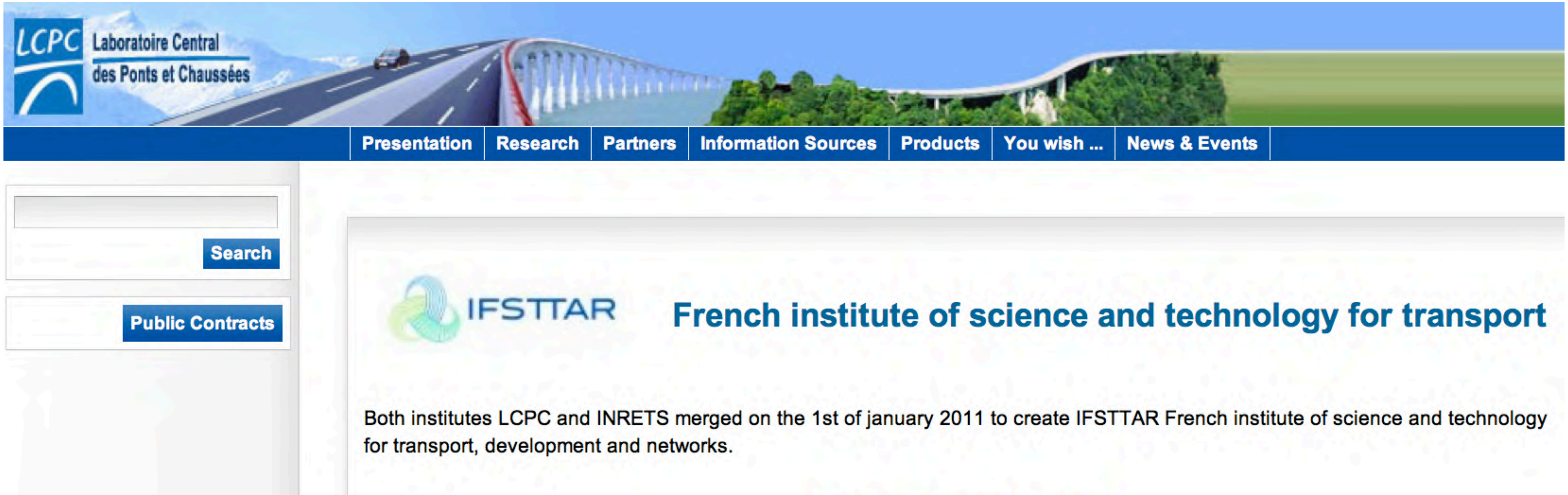
Public Contracts

IFSTTAR

French institute of science and technology for transport

Both institutes LCPC and INRETS merged on the 1st of january 2011 to create IFSTTAR French institute of science and technology for transport, development and networks.

http://www.ifsttar.fr



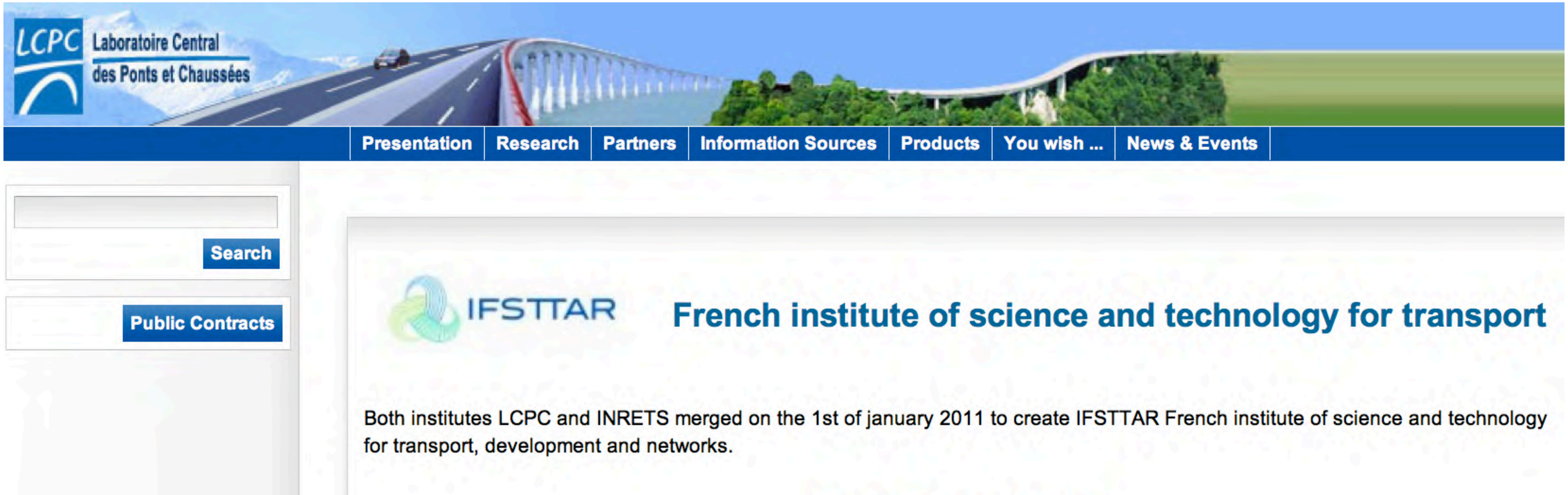
École des Ponts ParisTech

LAFARGE

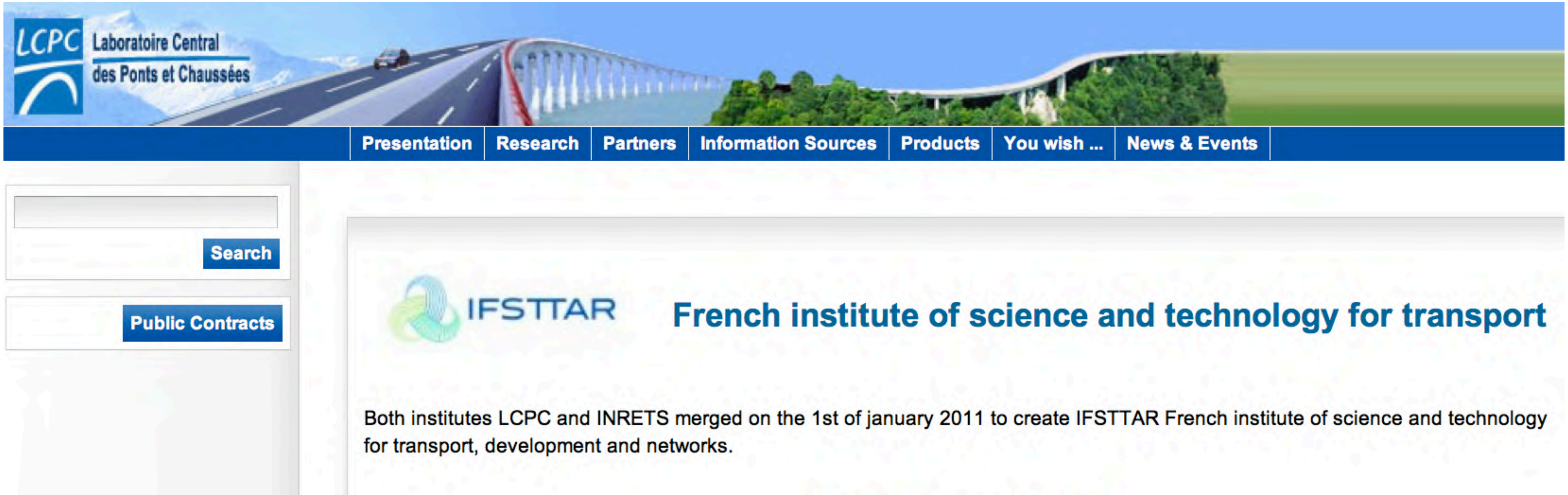
COMMUNIQUE DE PRESSE

Paris, le 9 juin 2011

LAFARGE ET L'ÉCOLE DES PONTS PARISTECH RENFORCENT LEUR PARTENARIAT



LAFARGE vient de signer un contrat-cadre avec le Laboratoire Navier, unité de recherche dans le domaine de la mécanique et de la physique des matériaux, des structures et des géomatériaux, qui rassemble des chercheurs de haut niveau de l'École des Ponts ParisTech, du CNRS et de l'**IFSTTAR**. Dans le cadre de cette collaboration, le Laboratoire Navier contribuera aux recherches sur les propriétés de mise en œuvre, les performances mécaniques et la durabilité des nouveaux bétons développés par Lafarge pour une construction à faible empreinte carbone.



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p
d
développés par Lafarge pour une construction à faible empreinte carbone.

R&D on the new cements/concretes **developed by Lafarge** targeting low-carbon footprint.

This study sponsored by LAFARGE to denigrate geopolymer cements, ignores deliberately the geopolymer cements industrialized, namely:

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-Poly(sialate-siloxo) ROCK-BASED cements (2003) by Cordi-Géopolymère, France

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-E-CRETE Geopolymer Concrete developed by Zeobond Australia (2007)

CO_2 reduction for

CO_2 reduction for Rock-based GP-cement

CO_2 reduction for Rock-based GP-cement

(1) by-products (waste)

CO_2 reduction for Rock-based GP-cement

(1) by-products (waste)

(2) all ingredients manufactured

Slag as by-product (waste) and with K-silicate solution

Slag as by-product (waste) and with K-silicate solution

Processing	**Portland Cement**	**GP-cement uncalcined**	**GP-cement calcined**
calcination	1,000	0,035	0,140
crushing	0,020	0,018	0,018
K-silicate	0	0,050	0,050
Slag waste	0	0	0
total	1,020	0,103	0,208
reduction	0	90 %	80 %

Slag manufactured and with K-silicate solution

Slag manufactured and with K-silicate solution

Processing	Portland Cement	GP-cement uncalcined	GP-cement calcined
calcination	1,000	0,035	0,140
crushing	0,020	0,018	0,018
K-silicate	0	0,050	0,050
Slag manuf.	0	0,100	0,100
total	1,020	0,203	0,308
reduction	0	80 %	70 %

Slag as by-product (waste) and with GP-LAVA

Slag as by-product (waste) and with GP-LAVA

Processing	Portland Cement	GP-cement uncalcined	GP-cement calcined
calcination	1,000	0,035	0,140
crushing	0,020	0,018	0,018
GP-LAVA	0	0,100	0,100
Slag waste	0	0	0
total	1,020	0,153	0,258
reduction	0	85 %	75 %

Slag manufactured and with GP-LAVA

Slag manufactured and with GP-LAVA

Processing	Portland Cement	GP-cement uncalcined	GP-cement calcined
calcination	1,000	0,035	0,140
crushing	0,020	0,018	0,018
GP-LAVA	0	0,100	0,100
Slag manuf.	0	0,100	0,100
total	1,020	0,253	0,358
reduction	0	75 %	65 %

CO2 reduction

Lafarge Portland cement

CO2 reduction

Lafarge Portland cement

best case: 25%

CO2 reduction

Lafarge Portland cement

best case: 25%

Rock-based Geopolymer cement

CO2 reduction

Lafarge Portland cement

best case: 25%

Rock-based Geopolymer cement

worse case: 65%

CO2 reduction

Lafarge Portland cement

best case: 25%

Rock-based Geopolymer cement

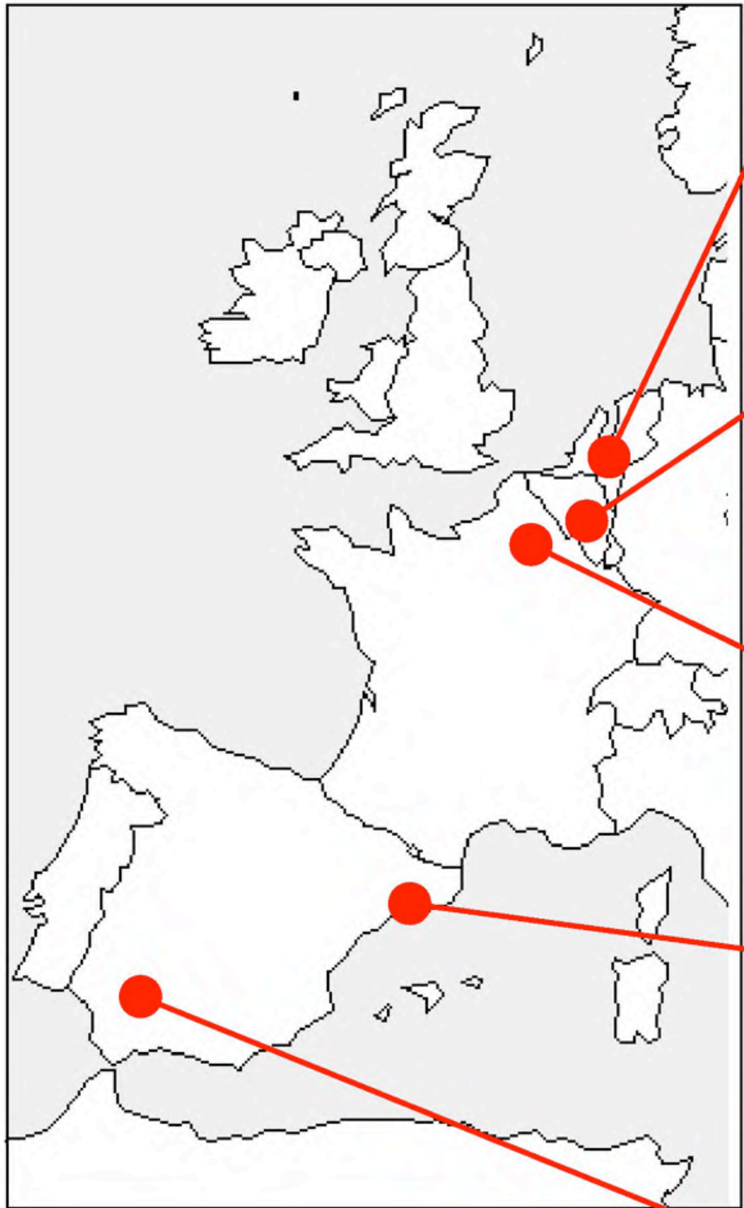
worse case: 65%

best case: 90 %

(3)

Fly ash / slag - based geopolymer cement

GEOASH



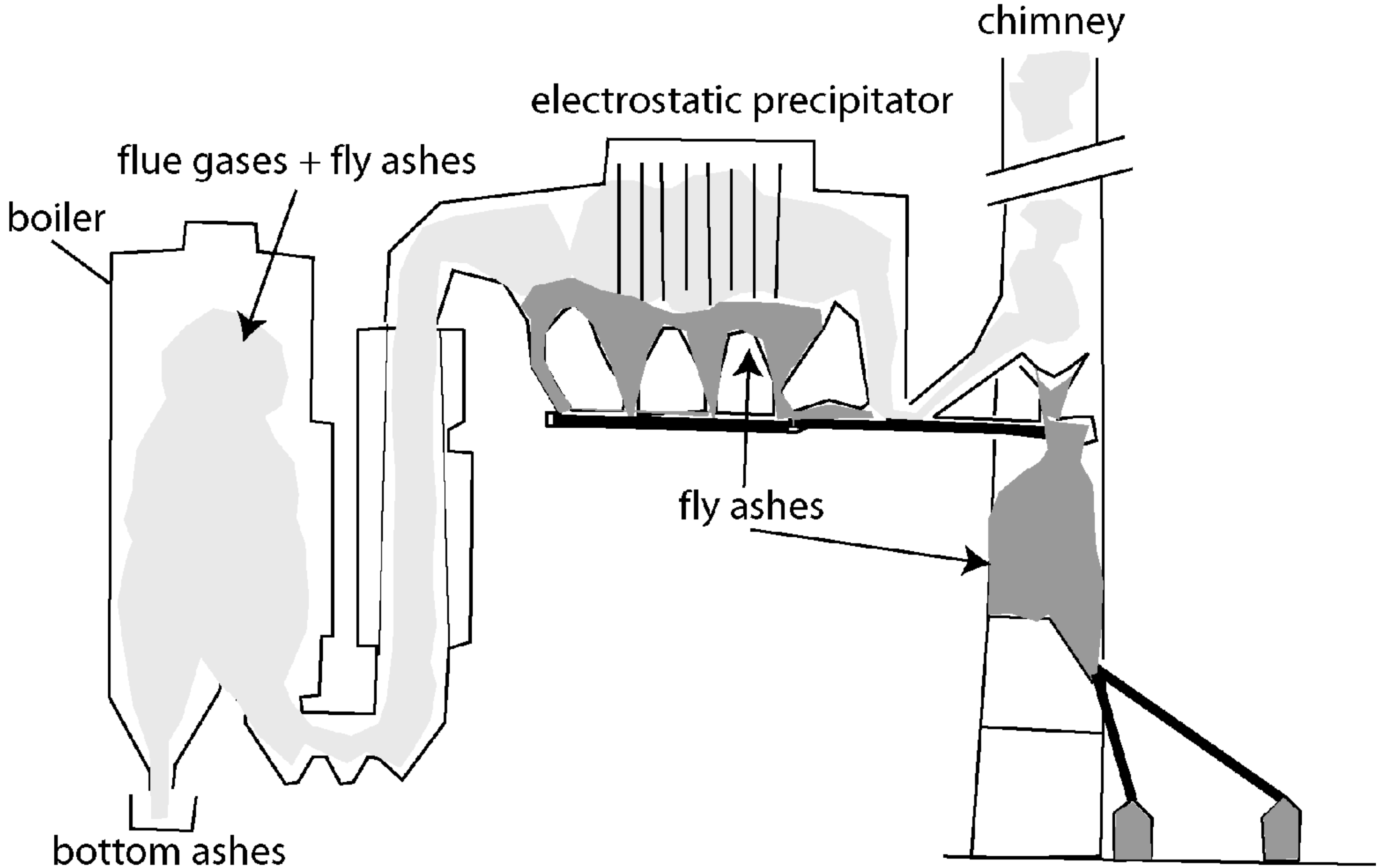
Nederlands
Delft University of Technology
TU DelfT, DELFT

Belgium
Institut Scientifique
de Service Public
ISSEP, LIÈGE

France
Cordi-Géopolymère
SAINT-QUENTIN

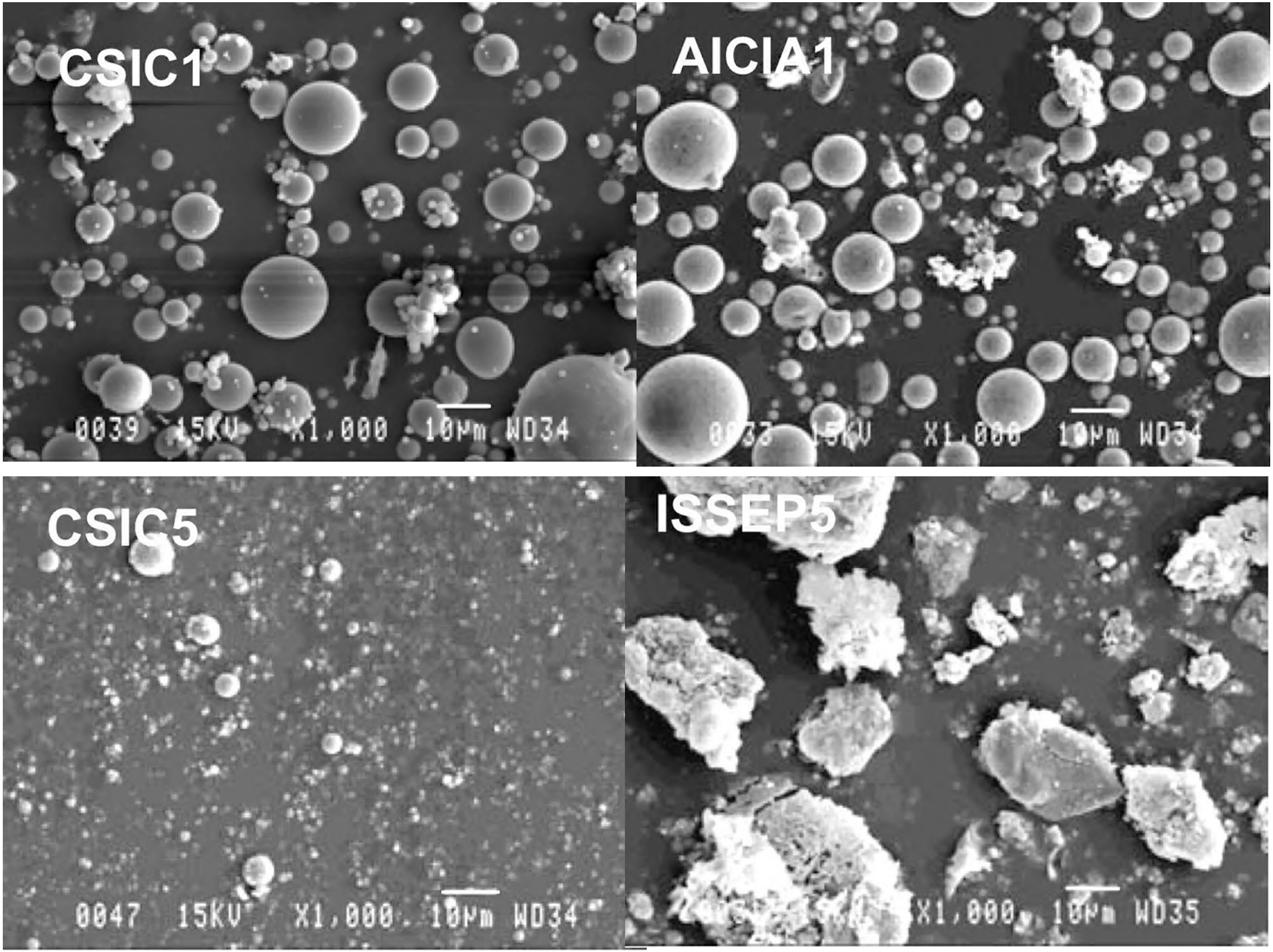
Spain
Consejo Superior de
Investigationes
Scientificas, BARCELONE

Spain
Ass. Cooperacion Ind. Andalucia
SÈVILLE


chimney
electrostatic precipitator
flue gases + fly ashes
boiler
fly ashes
bottom ashes

Combustion technologies and operating temperatures

Technology	Temperature
fluidized-bed	850°C
pulverized coal combustion 1	1250°C
pulverized coal combustion 2	1500°C
Coal gasification IGCC	1800°C


CSIC1
0039 15KV X1,000 10μm WD34
AICIA1
X1,000 10μm WD34
CSIC5
0047 15KV X1,000 10μm WD34
ISSEP5
X1,000 10μm WD35

COAL FLY-ASH GEOPOLYMERIZATION

COAL FLY-ASH

GEOPOLYMERIZATION

Hardening at Room-Temperature
Based on
(K,Ca)-poly(sialate-siloxo) matrix

Conventional method: alkali-activation

Conventional method: alkali-activation

dissolution and zeolite formation

Conventional method: alkali-activation

dissolution and zeolite formation

- 0.3-0.4 L/kg, NaOH 12M,

Conventional method: alkali-activation

dissolution and zeolite formation

- 0.3-0.4 L/kg, NaOH 12M,
- 24h room temperature ageing,

Conventional method: alkali-activation

dissolution and zeolite formation

- 0.3-0.4 L/kg, NaOH 12M,

- 24h room temperature ageing,

- curing at 80^{o}C for 48h.

Conventional method: alkali-activation

dissolution and zeolite formation

- 0.3-0.4 L/kg, NaOH 12M,
- 24h room temperature ageing,
- curing at 80^{o}C for 48h.

User-hostile

Geopolymeric method:

Geopolymeric method:

room temperature hardening

Geopolymeric method:

room temperature hardening

polycondensation

Geopolymeric method:

room temperature hardening polycondensation

- fly ash…………………………………..50 to 85

Geopolymeric method:

room temperature hardening polycondensation

- fly ash……………………………..50 to 85
- K-silicate solution $SiO_2:K_2O > 1.4$……..10

Geopolymeric method:

room temperature hardening polycondensation

- fly ash…………………………………..50 to 85
- K-silicate solution SiO_2:K_2O >1.4……..10
- blast furnace slag…………………………...15

Geopolymeric method:

room temperature hardening polycondensation

- fly ash……………………………..50 to 85
- K-silicate solution $SiO_2:K_2O$ >1.4……..10
- blast furnace slag…………………….....15
- water……………………………………5

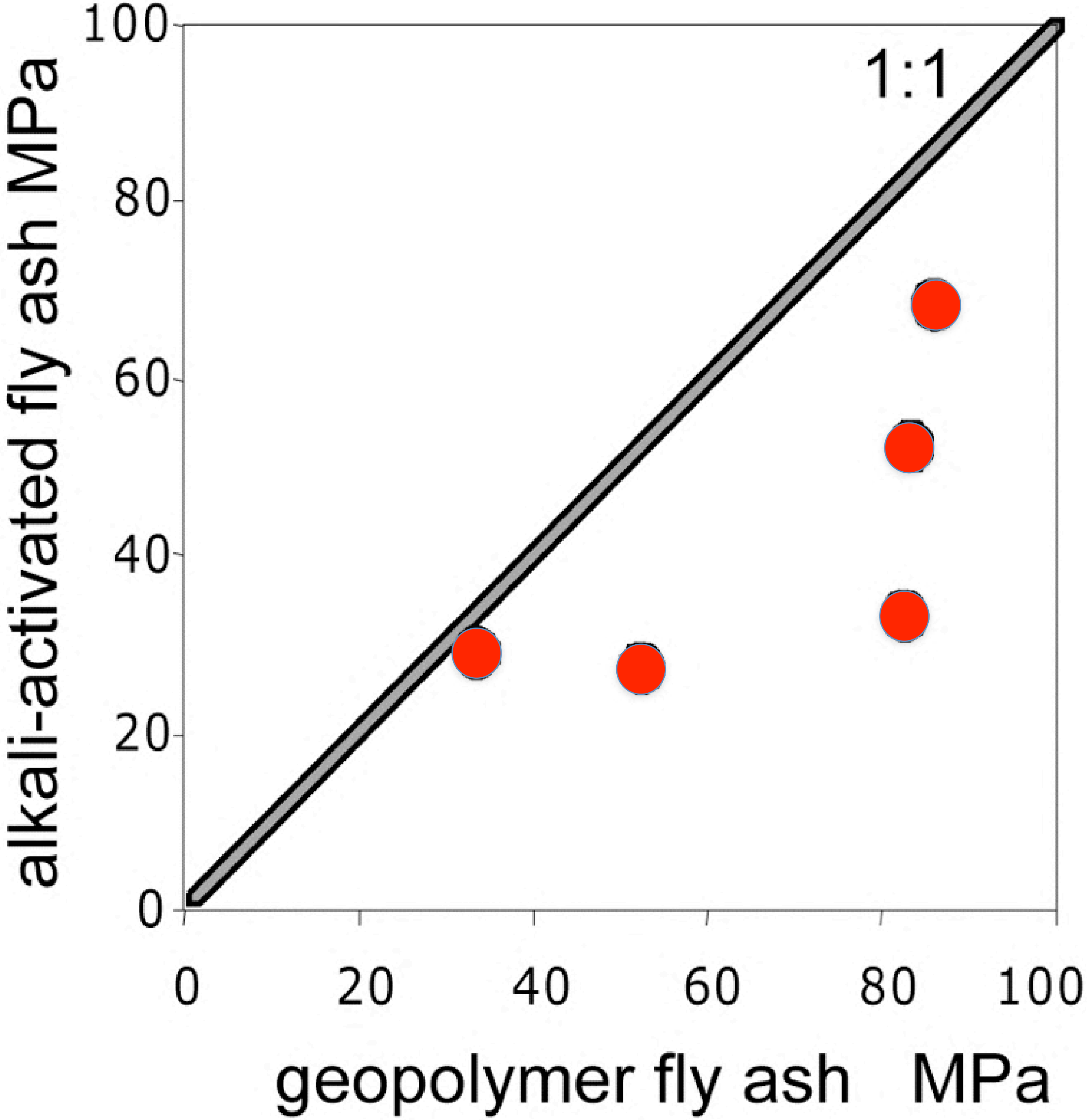
Geopolymeric method:

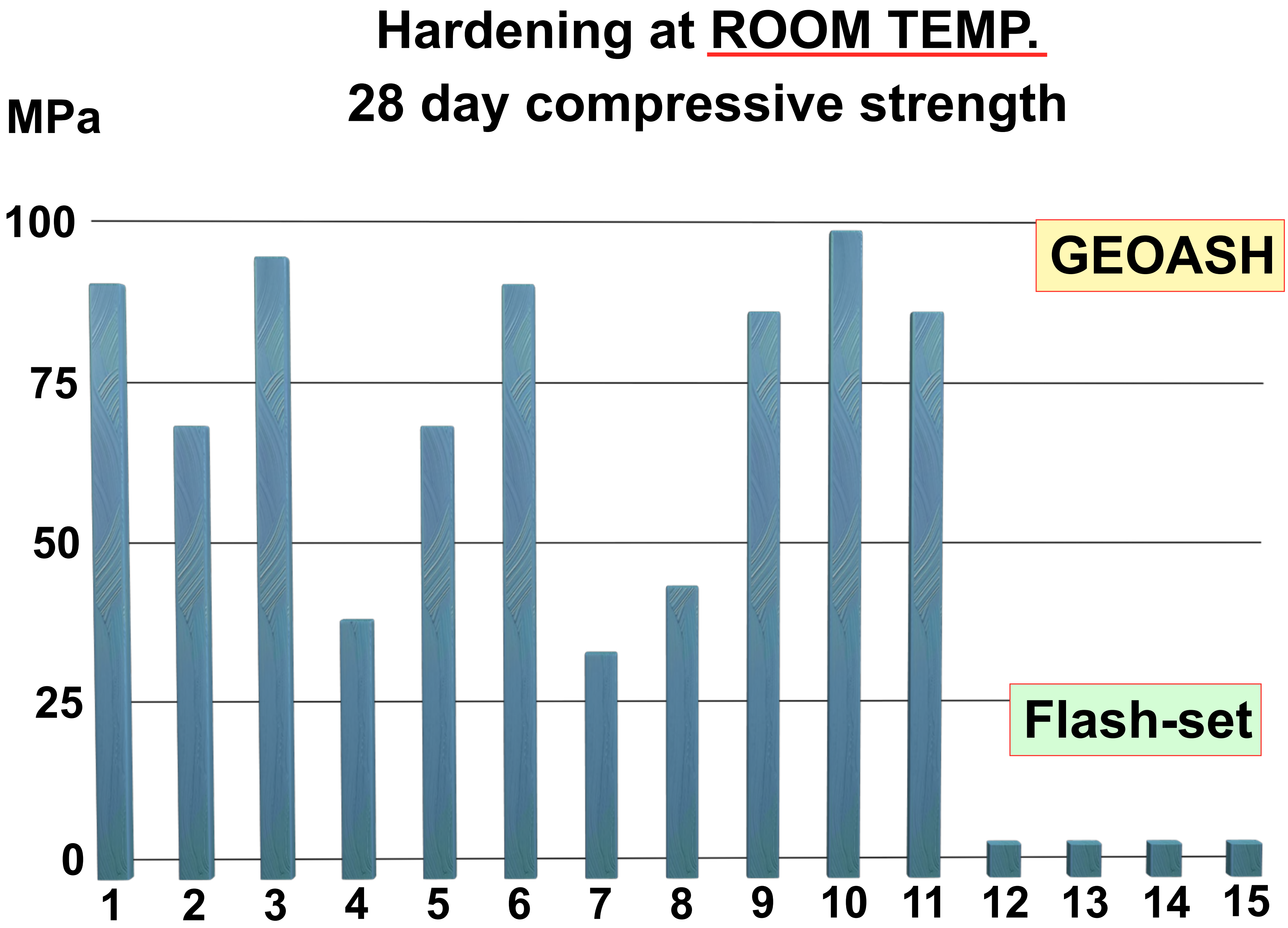
room temperature hardening polycondensation

- fly ash…………………………….50 to 85
- K-silicate solution SiO2:K2O >1.4……..10
- blast furnace slag………………………..15
- water……………………………………..5

User-friendly.

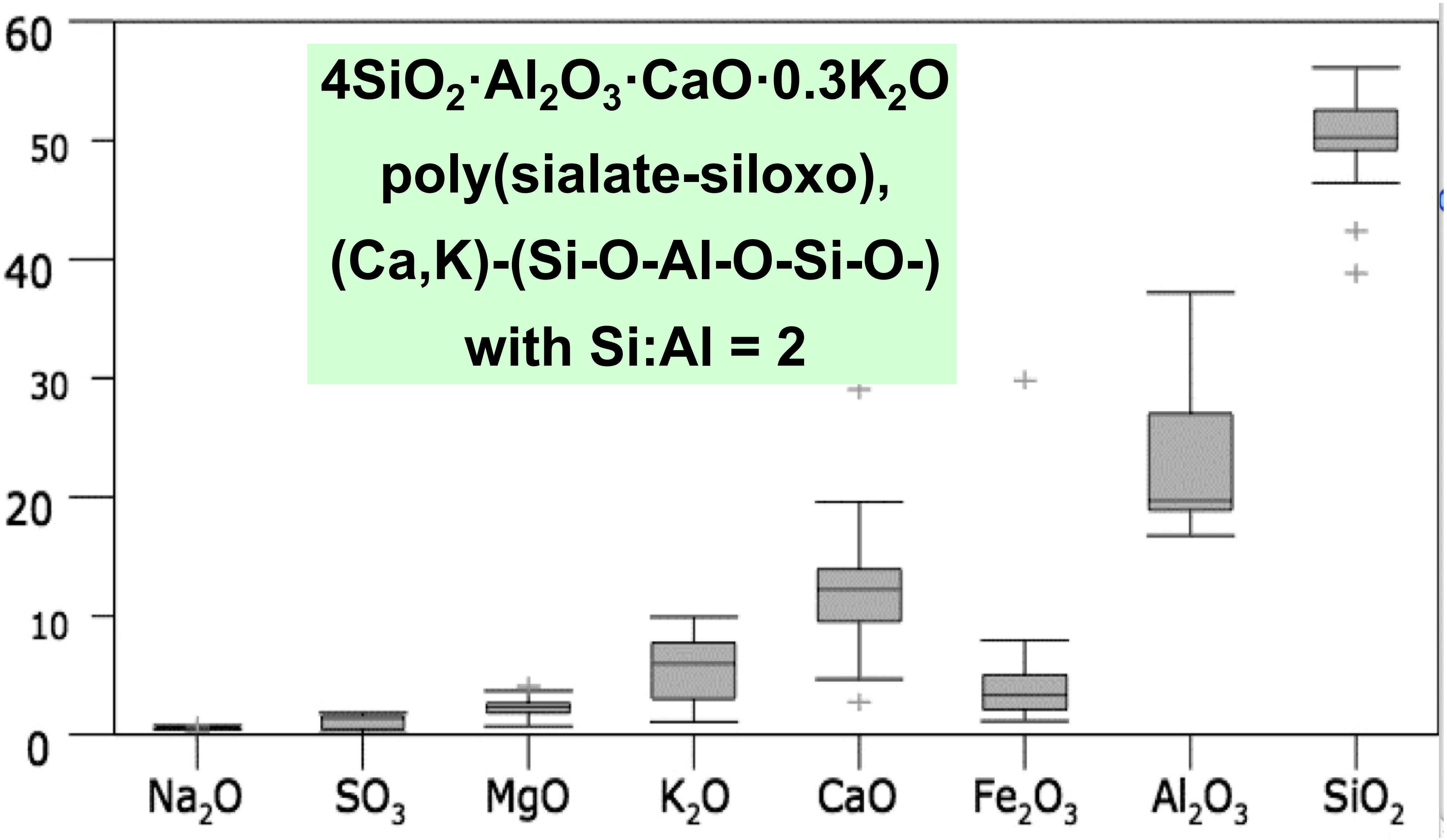
28 day compressive strength

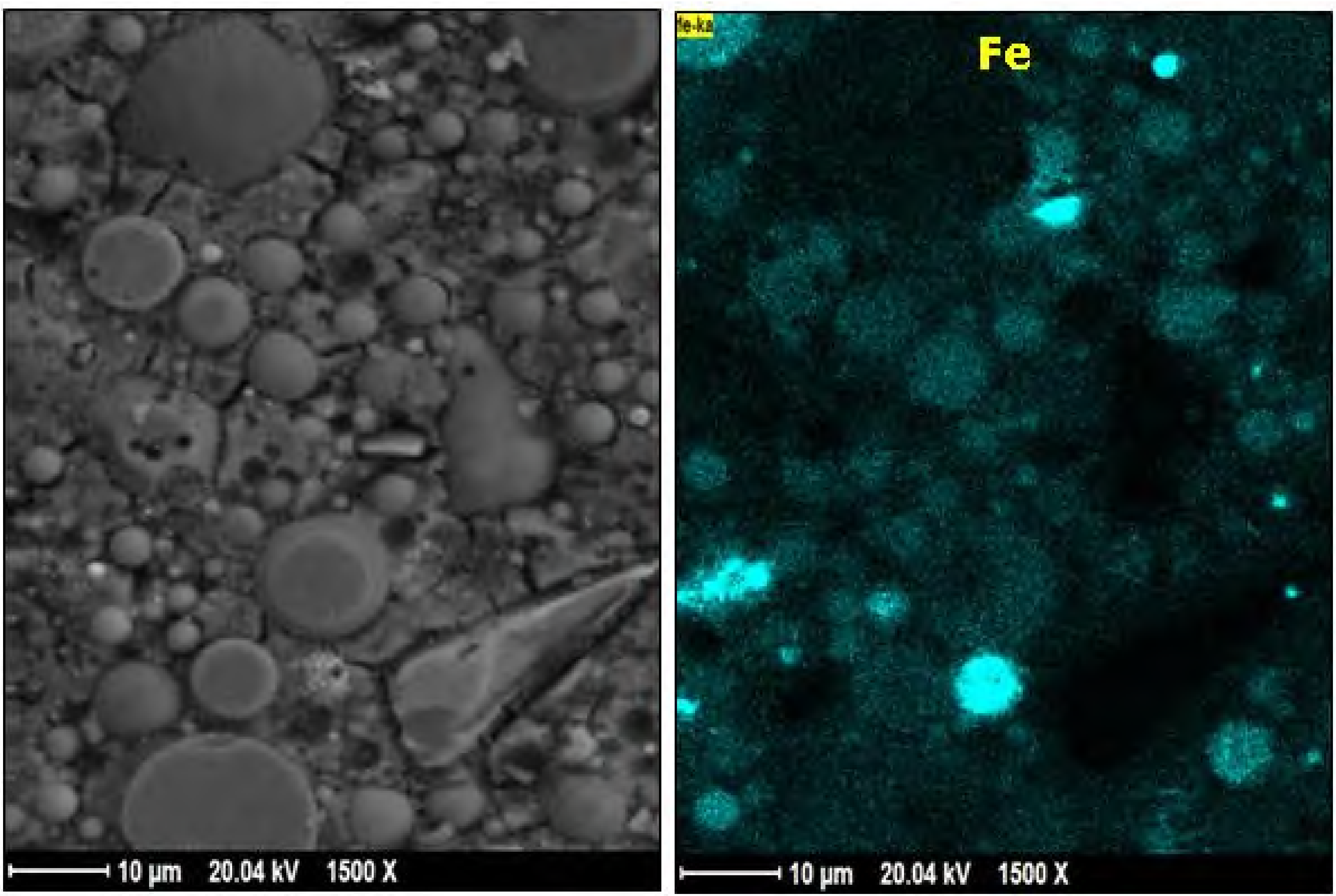


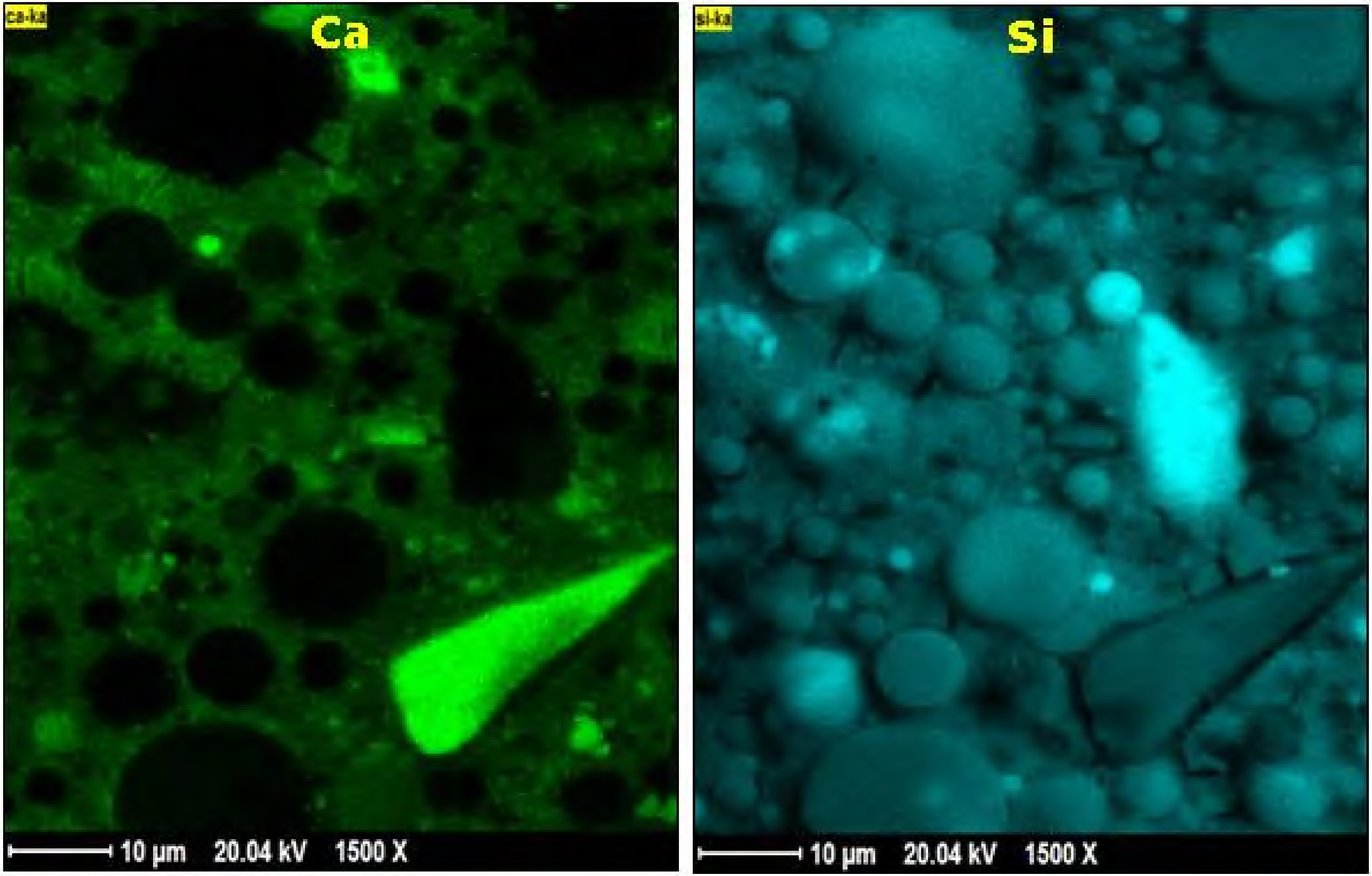


Hardening at ROOM TEMP.
28 day compressive strength
MPa
100
75
50
25
0
GEOASH
Flash-set
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Ca-based geopolymer fly ash matrix composition




10 µm 20.04 kV 1500 X
Fe
10 µm 20.04 kV 1500 X


ca-ka
Ca
10 µm 20.04 kV 1500 X
si-ka
Si
10 µm 20.04 kV 1500 X

From Low-Tech

to High-Tech Development

of USER-FRIENDLY systems

pH

pH

CORROSIVE

IRRITANT

User- hostile

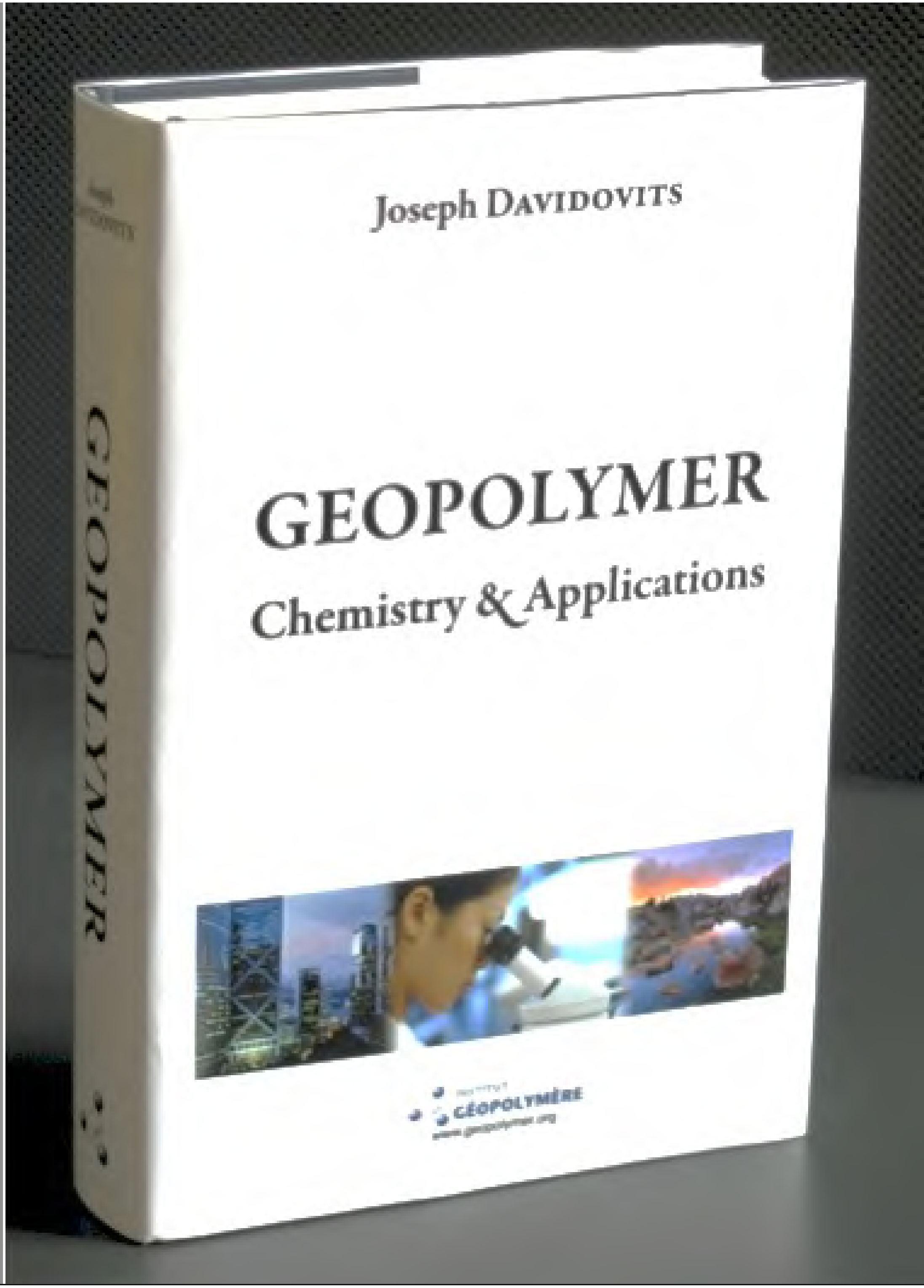
Systems

User- friendly

Systems

Corrosive and irritant chemicals

Hostile	Friendly
CaO (quick lime) NaOH KOH	$Ca(OH)_2$ Portland cement Iron slag
Sodium metasilicate $SiO_2:Na_2O = 1$	Slurry soluble silicate/ kaolin MR $1.25 < SiO_2:M_2O < 1.45$
Any soluble silicate MR $SiO_2:M_2O < 1.45$	Any soluble silicate MR $SiO_2:M_2O > 1.45$


Joseph DAVIDOVITS
GEOPOLYMER
Chemistry & Applications
GEOPOLYMER
GÉOPOLYMÈRE