Geopolymers and Radioactive Waste Containement

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Purpose and Objectives

❖ Synthesis of the selected matrix
- Selecting source materials for the encapsulation matrix
- Optimization and validation

❖ Encapsulation of radioactive waste
- Research of a suitable matrix in agreement with Waste Acceptance Criteria (WAC)
- Validation tests

Preface

- What is radioactive waste and how is it managed?
- What is the chosen matrix? What are the precursors?
- Experiments
- Results and progress of the work

Radioactive Waste Management

Low Level Waste [1]

- Protective clothing, wiping rags, reactor water treatment residues, equipment, tools
- Short-lived radionuclides Be-7, Na-24, K-42, <10^6 Bq/g
- Typically does not require shielding during handling and transport
- **Cementation** [3,4]

Intermediate Level Waste [2]

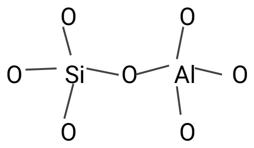
- Resins, chemical sludges, metal fuel cladding, and contaminated materials from reactor decommissioning
- May contain significant amounts of long-lived radionuclides Cs-137, Co-60, Sr-90, from 10^6 to 10^9 Bq/g
- Requires shielding during handling, transport and disposal
- **Polymer encapsulation**[3]
- **Ceramic encapsulation** [3, 4, 5]

High Level Waste [3]

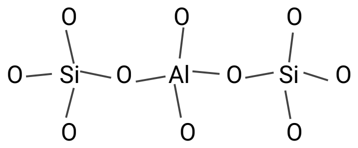
- Reprocessing waste
- Small volume, strong radioactivity
- Requires heavy shielding and cooling
- long-lived radionuclides Pu-239, U-236, Cs-135, >several billion becquerels per gram
- Requires permanent deep geological disposal
- **Vitrification**[6]

Geopolymer

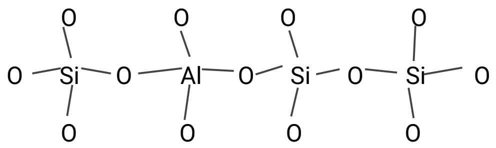
Silica source	Alumina source	Activator
Diatomaceous earth*[9]**, Rice husk ash[7], ***Sepiolite	red mud[8], bauxite	Lime (CaO, $Ca(OH)_2$)[9], **NaOH**[10], KOH[10], **Na_2SiO_3**[10], K_2SiO_3[10]
Fly ash[10], blast furnace slag[10], ***metakaolin***[10], ***kaolin***[10]		



Polysialate Si/Al=1 [11]



Poly(sialate-siloxo) Si/Al=2 [11]

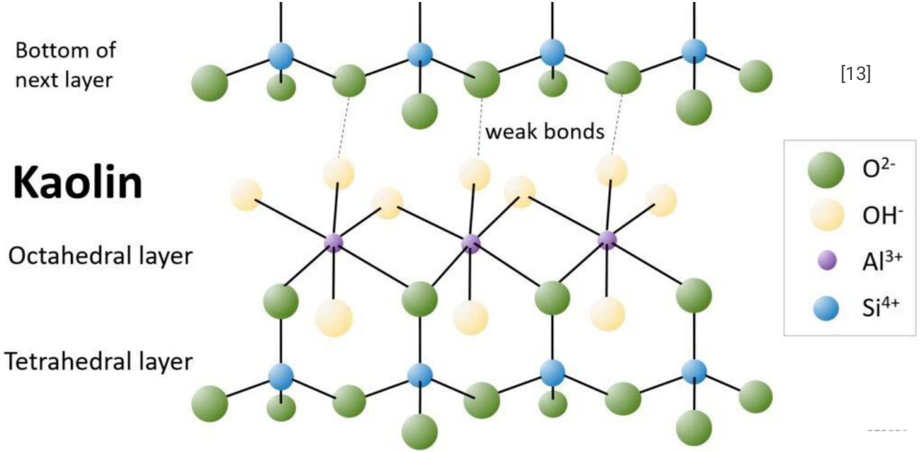


Poly(sialate-disiloxo) Si/Al=3 [11]

Geopolymers are inorganic materials produced by low-temperature polymerization of an aluminosilicate precursor in an alkaline solution.[10]

Kaolin

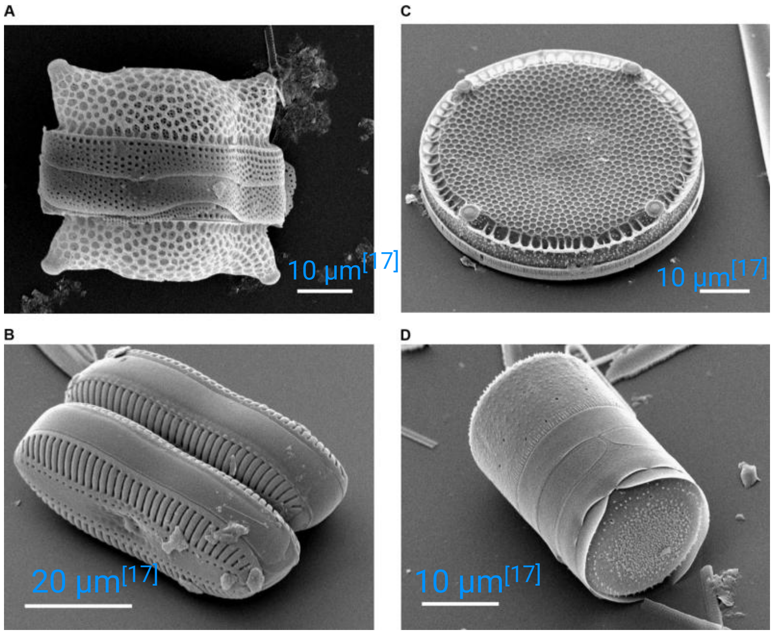
- Clay mineral, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$
- One tetrahedral sheet of silica (SiO_4)
- One octahedral sheet of alumina (Al_2O_3) [12]



[13]

Diatomaceous Earth

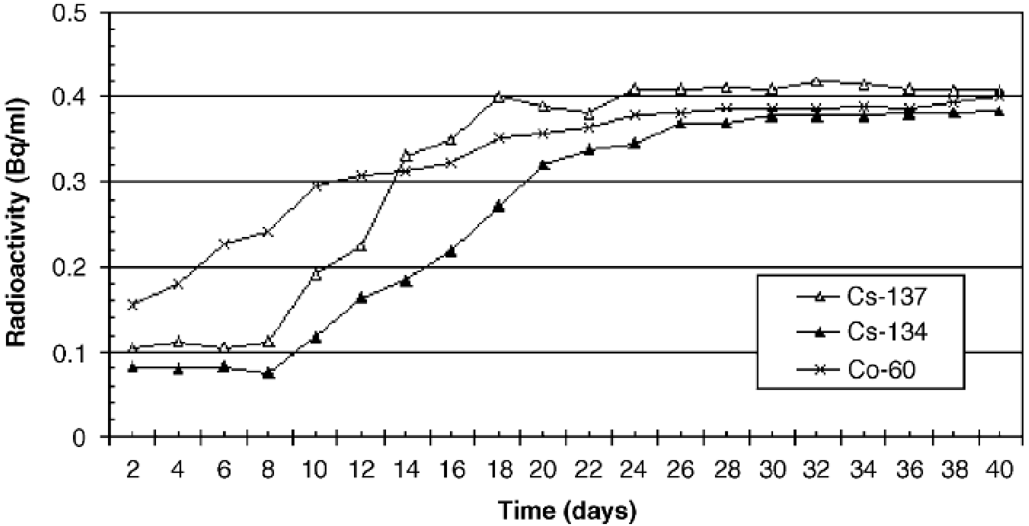
- Consists of the fossilized remains of diatoms[14]
- Siliceous sedimentary rock, usually light in color[14]
- Increase in compressive strength in geopolymers[10]



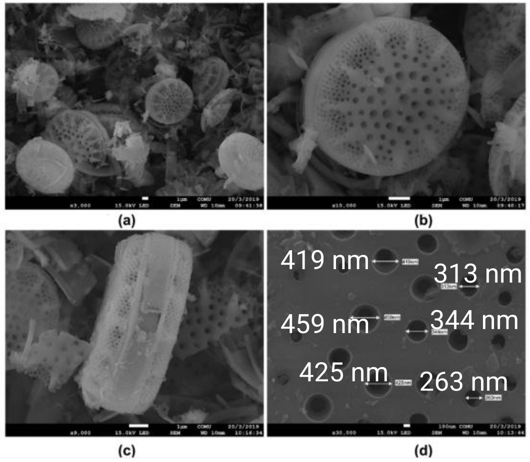
Composition	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	TiO_2	CaO	MnO	P_2O_5	SO_3
Contents, %	67.34[15]	15.51[15]	2.90[15]	1.52[15]	2.22[15]	1.43[15]	0.69[15]	0.79[15]	0.02[15]	0.16[15]	0.48[15]
	86.03[16]	3.01[16]	2.89[16]	0.69[16]	0.28[16]	0.19[16]	0.20[16]	0.76[16]	0.06[16]	0.15[16]	—[16]

the highest and lowest amounts of diatomaceous earth's chemical composition

Retention on Diatomaceous Earth



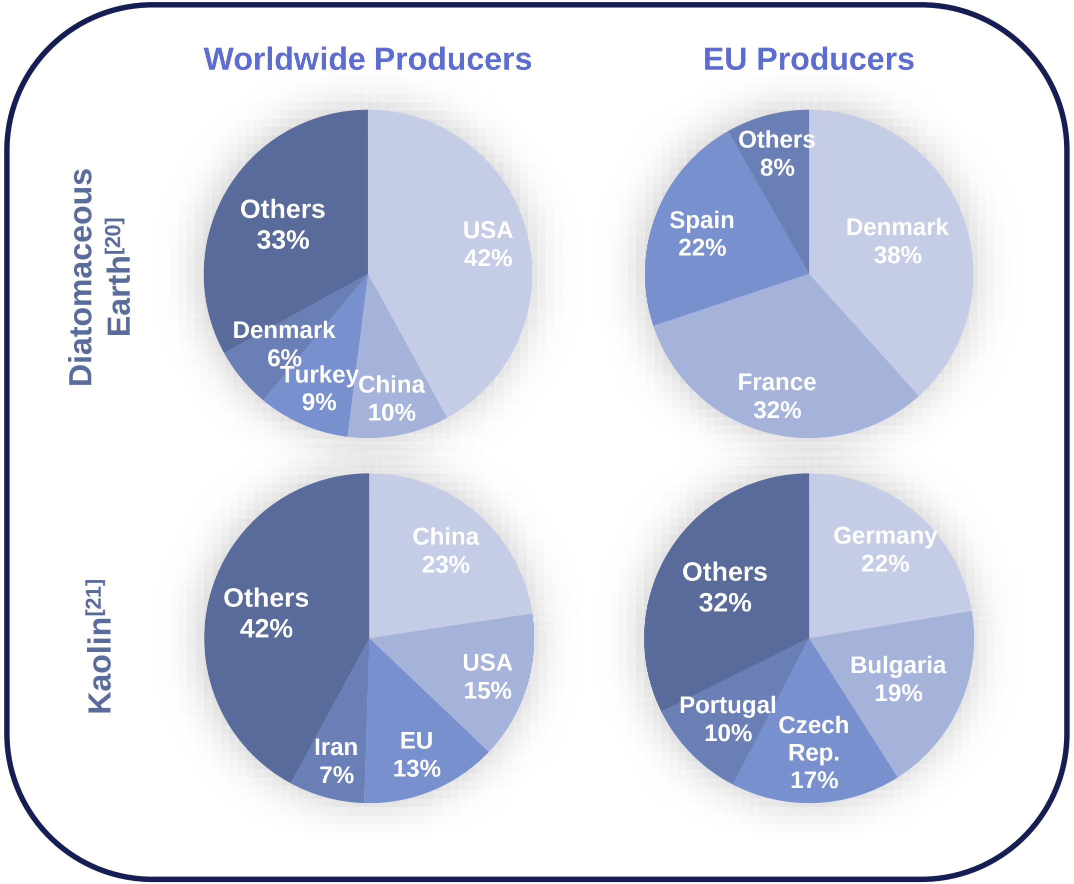
Transmitted radioactivity as a function of time [18]

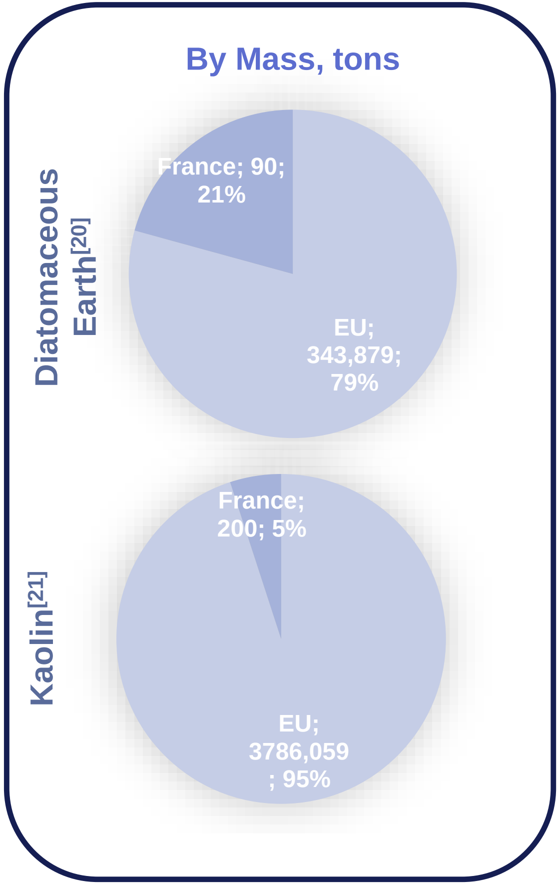


SEM review of DE [19]

- 1 m^3 liquid waste (Cs-137, Cs-134 and Co-60)
- Radioactivity reduced by 85% (from 2.60 bq/ml to 0.40 bq/ml)
- 100 liters of diatomite
- Subject to testing again

Raw Material Supply Chain, 2021





Why Geopolymer?

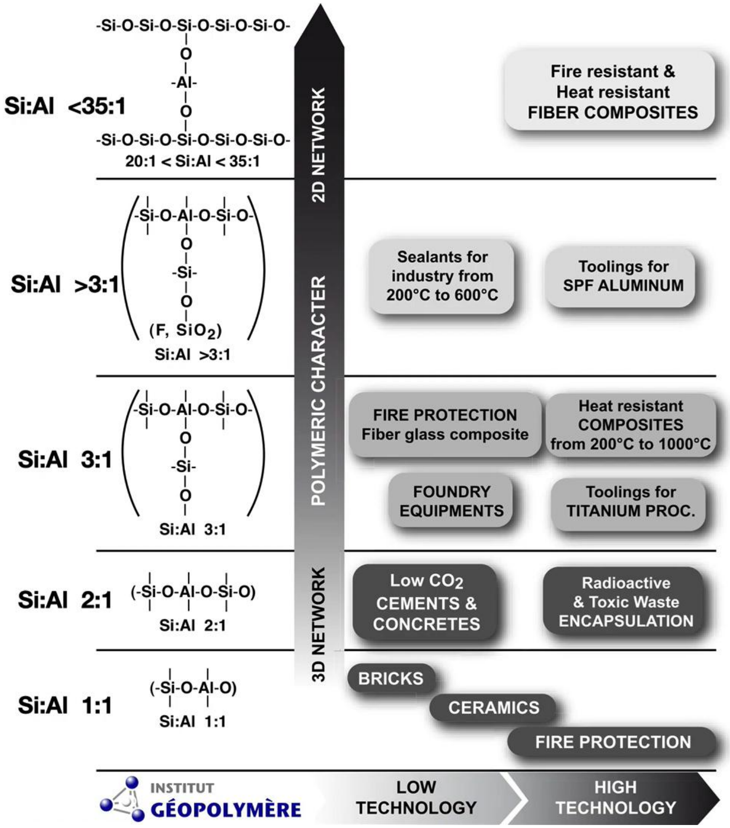
Advantages

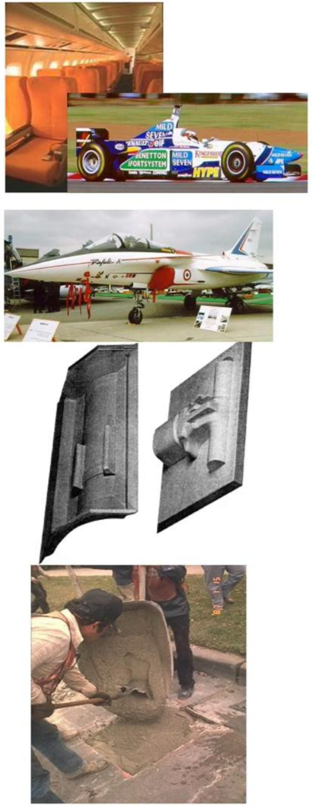
- Lower CO_2 emissions [22, 23]
- Utilization of waste materials [22, 23, 24]
- Improved durability [24, 25]
- Rapid strength gain [23]
- Lower energy consumption [22, 26]

Disadvantages - Limitations

- Drying shrinkage and cracking [27]
- Efflorescence [27]
- Needs expertise
- Not ready for production
- Unknown reaction mechanism

Si/Al Ratio for Geopolymer Production[28]





[29]

SiO_2/Al_2O_3	3.50–4.50
Na_2O/Al_2O_3	0.80–1.20
H_2O/Na_2O	15–17.50
Na_2O/SiO_2	0.20–0.28

Geopolymer Samples, Optimized

Diatomaceous earth (DE)

600°C

3h

DE600, powder

25%

75%

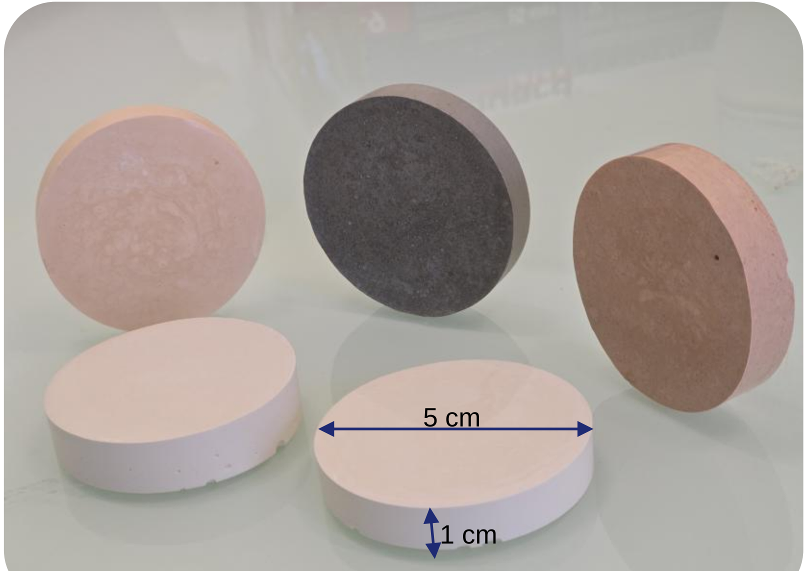
4M Na_2SiO_3, 1,5xSiO_2

Kaolin

800°C

5h

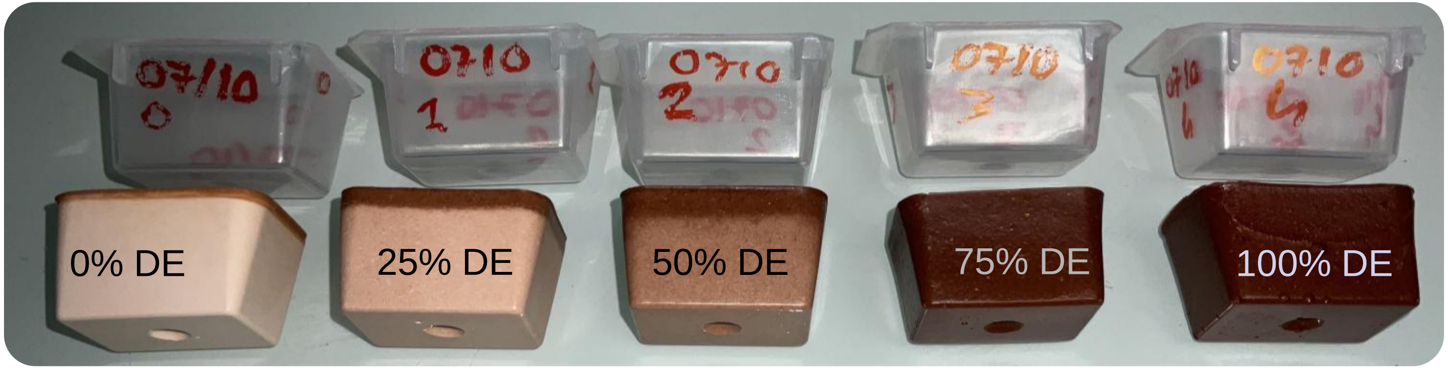
Metakaolin (MK)

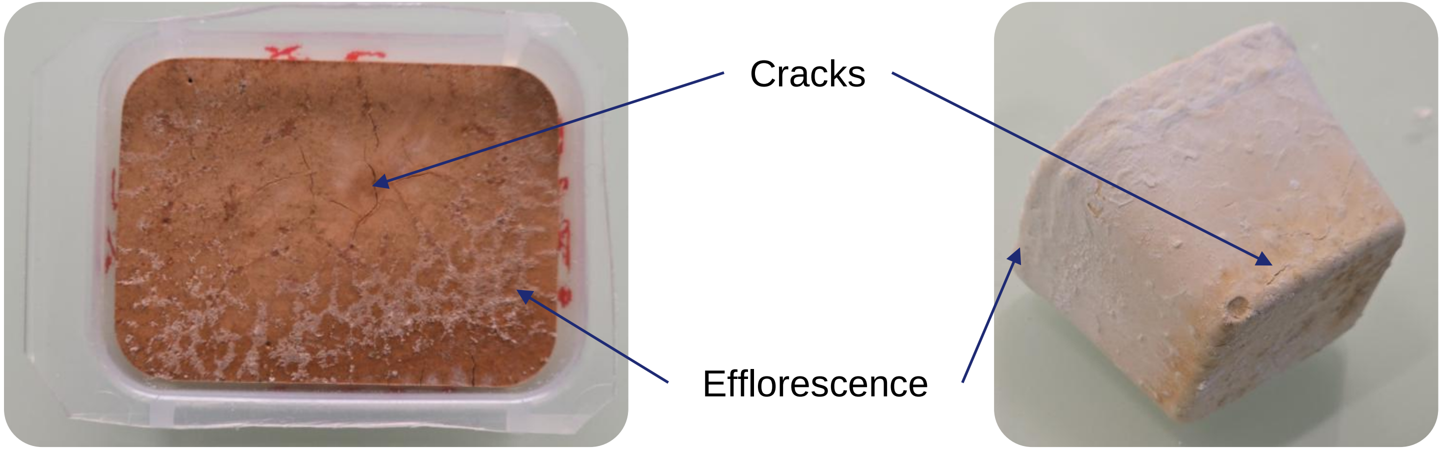


Geopolymers

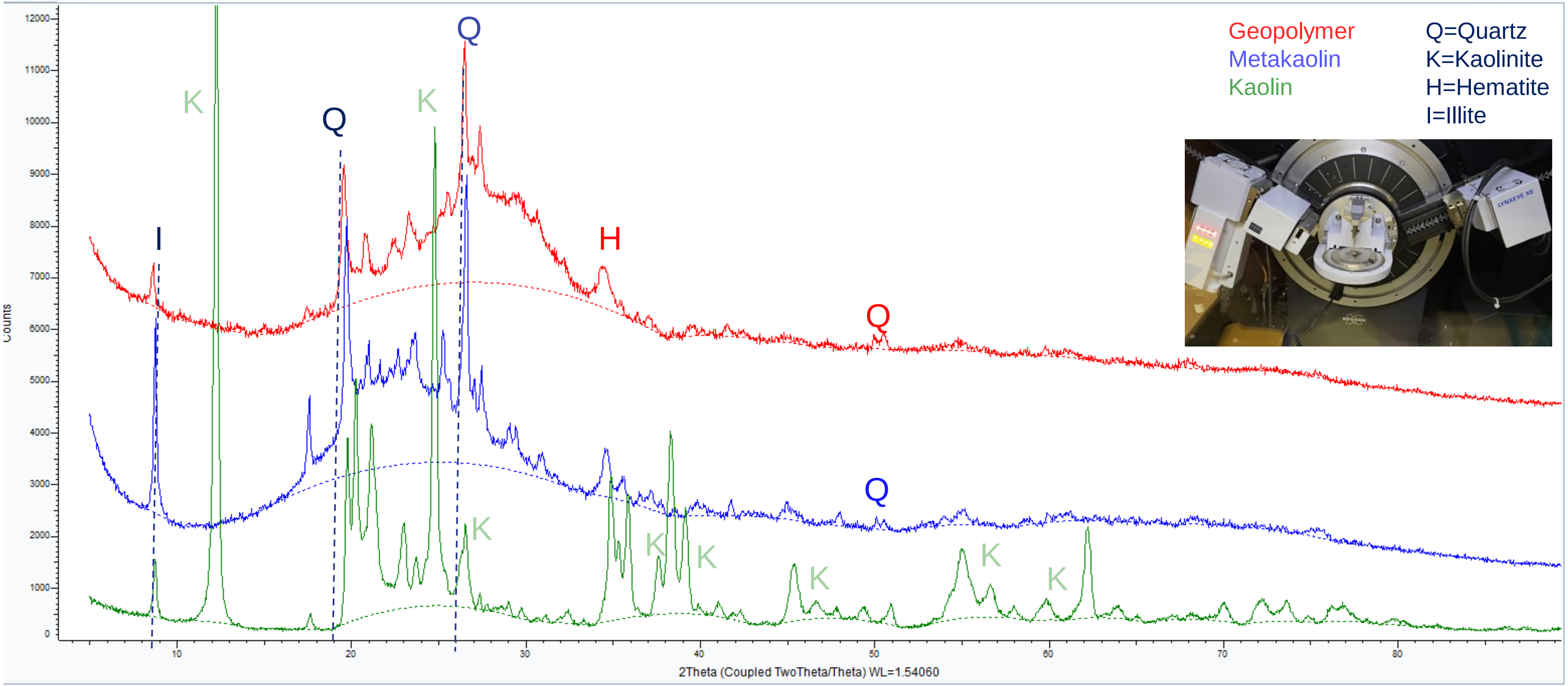
- Diatomaceous earth (DE) calcined at 600°C for 3h then crushed
- Kaolin calcined at 800°C for 5h to produce metakaolin (MK)
- Precursors, DE and MK, mixed at different percentages
- Activator, 4M Na_2SiO_3, added, mixed and molded
- Si/Al: 1,48 Na/Al: 0,97 H_2O/Na: 0,81 Na/Si: 0,65

Geopolymer Samples, First Attempts

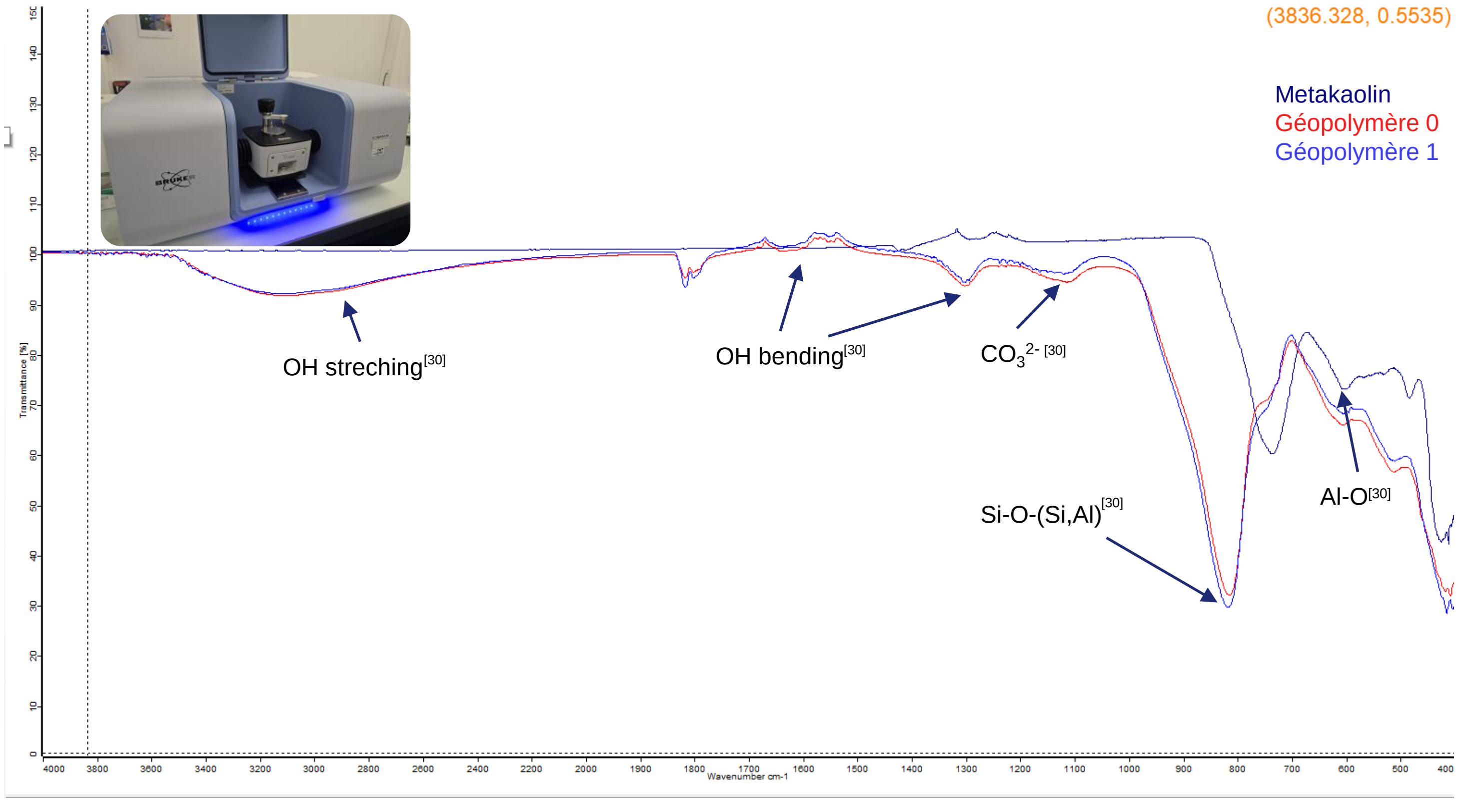




XRD Results


Geopolymer
Metakaolin
Kaolin
Q=Quartz
K=Kaolinite
H=Hematite
I=Illite
Q
K
Q
K
I
H
Q
Q
K
K
K
K
K
K
Counts
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50
60
70
80
2Theta (Coupled TwoTheta/Theta) WL=1.54060

FTIR Results



Progress of the Work

2024
First Half

Start

- Source material selection and characterisation

2024
Second Half

Analyses and Production

- FTIR, XRD
- Collaboration with POLIMI
- Formulation and optimisation tests
- First generation geopolymers

2025
First Half

Developement

- Collaboration with l'Université Aix Marseille
- New material; Bauxite residues
- More characterization
- Mechanical tests

2025
Second Half

Recursion

- More tests

THANK YOU!

Any questions?

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