IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

The use of excavated soils into geopolymer binders

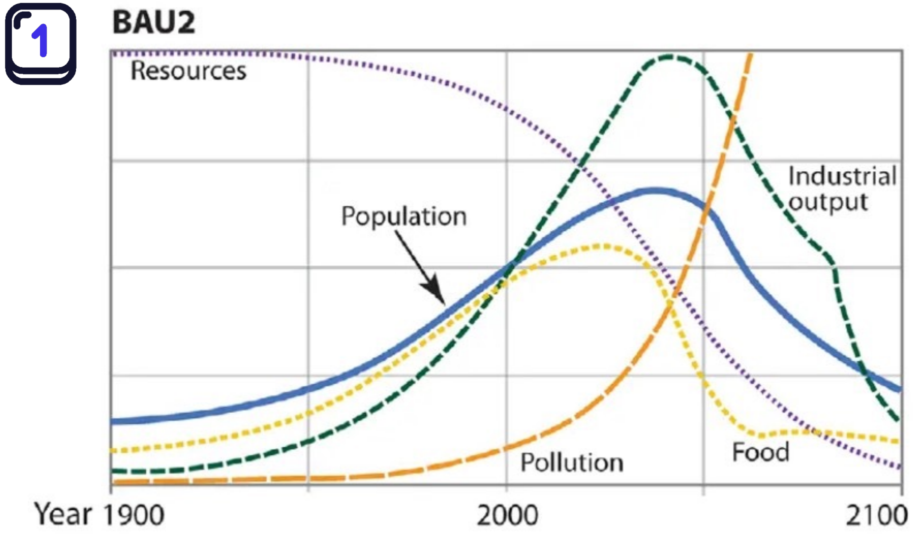
Saint Quentin

GP Camp 2023

Dr. Mouhamadou AMAR
Assistant Professor

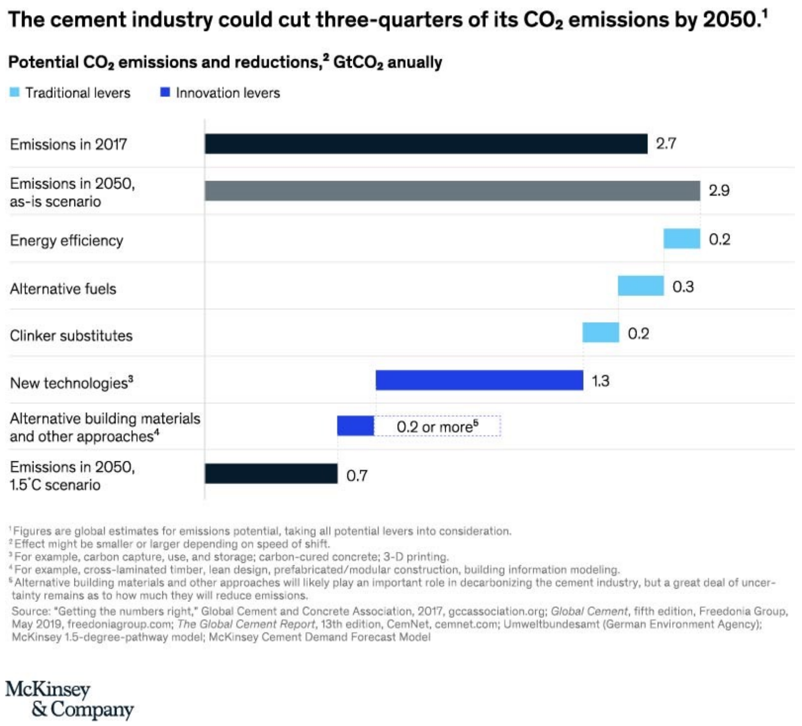
Context

1

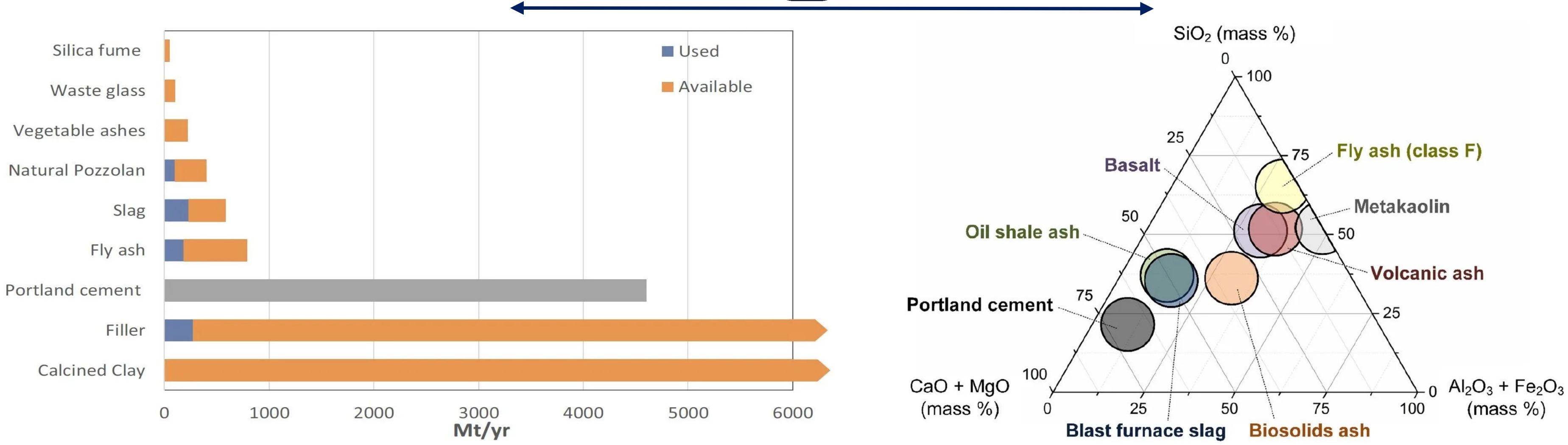


Le scénario BAU2 (business-as-usual), qui implique de continuer à vivre selon nos modèles actuels, montre un déclin drastique de la population et de ses différents indicateurs de qualité de vie, avec notamment une augmentation exponentielle de la pollution et des pénuries alimentaires. © Gaya Herrington, 2021

2



3



- Increase in human population and industry development
- Portland cement impact mitigation is needed → New techs and innovation
- Natural resources preservation

Methodology

Cement industry

OPC 1 ton | CO2 1 ton

5-7% of all man-made CO2 emissions

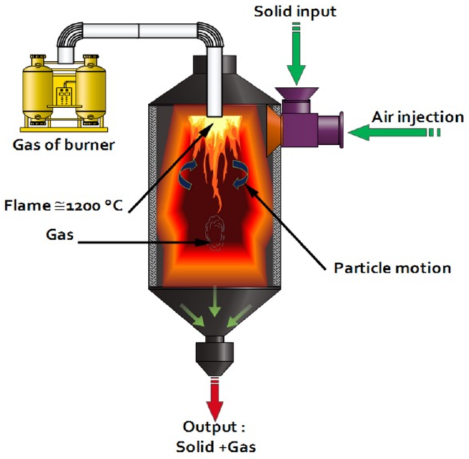
Excavated Materials

Excavated soils

130 million tons **per year**

Waste Materials

Treatment



Flash Calcination

Geopolymeric materials

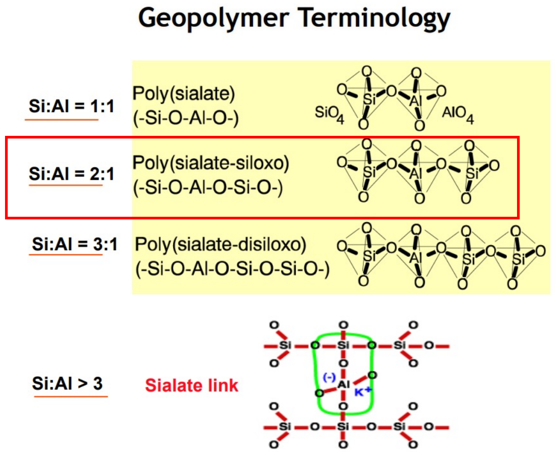
Geopolymer binders

Eco-friendly binders

IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

Geopolymer design

Geopolymer cement binders



Rigid 3D Macromolecular structure

↓

% chosen according to design

1. Precursor
   - MK → Stabilization
   - GBFS → Hardening
   - FCM → Silica/Alumina source
2. Alkaline Reagent → Potassium silicate (Geosil)

→ Proper Mixing

✓ **Note:** **In geopolymers the % of materials can't be chosen randomly or the chemistry of the geopolymer will be unknown !**

IMPORTANT

IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

- 3 steps methods of optimization
- Include cost calculation and chemistry

Geopolymer design

1 Material properties identification

Elements	MK	GBFS	FCS	FCC	LS
Si	27.40%	14.90%	20.80%	28.82%	22.00%
Al	16.50%	6.80%	6.70%	9.83%	11.30%
SiO2	58.60%	31.87%	44.49%	61.64%	47.00%
Al2O3	31.17%	12.00%	12.66%	18.60%	21.00%
Al2O3/3	*x*	*4.00%*	*4.22%*	*6.20%*	*7.00%*

Given	Values
M Al2O3 g/mol	101.96
M K2O g/mol	94.19
% K2O Geosil WG	21.48%
% SiO2 Geosil g/mol	23.10%
M liquid Silicate g	100
M SiO2 g/mol	60.1
M water g/mol	18.01

	AB	AV	AP
	8.50%	16.90%	27.18%
	3.10%	6.10%	11.86%
	18.18%	36.14%	36.15%
	5.85%	11.52%	11.52%
Al2O3/2	*2.93%*	*5.76%*	*5.76%*

2 Formulation design and optimization

0.376	-0.622	0.164	0.00
1.000	1.000	1.000	100.00%
1.000	0.000	0.000	50.00%

0.00
70.00%

Résultat : x =	50.00%	FCC	20.00%
y =	34.37%	MK	20.00%
z =	15.63%	GGBS	30.00%

50.00

x =	50.00%
y =	34.37%
z =	15.63%

20.00

x =	50.00%
y =	34.37%
z =	15.63%

RUN

3 Cost estimation

FCC/B	MK/B	GGBS/B
50.00%	34.37%	15.63%

		272.2 g	pour	2072.2 g			
		131.4 kg	pour	1.0 T	rho	rho GEOSIL	
		87.6 L	pour	1.0 T	2150 kg/m3	1500 kg/m3	
		87.6 L	pour	465.1 L	Prix fournisseur	MK	
		282.4 kg	pour	1.00 m3	2000.00 eur/T	100.00 eur/T	
		188.3 L	pour	1.0 m3	GGBFS	Prix ciment OPC	
		2.00 €	pour	1.0 kg	25.00 eur/T	142.86 eur/T	
		2,000.0 €	pour	1.00 T			
		0.54 €	pour	272.2 g			
		2.00 €	pour	1.0 kg			
Price	SILICATES	262.7 €	pour	1.0 T		volume/3 samples	877.2911051
		262.7 €	pour	465.1 L		dosage OPC	513 kg/m3
		564.8 €	pour	1.0 m3	Prix OPC		
	MK	17.6 €	pour	1.0 m3	73.3 €	pour	1.0 m3
	GGBFS	2.0 €	pour	1.0 m3			
	Total	584.5 €	pour	1.0 m3	Différence de prix	***798%***	

Geopolymer mixing procedure

To ensure geopolymerization precessing

Mixing design procedure

Least reactive material + activator for 10 mins

Add MK for 5 mins

Add Slag which is most reactive so we add it at last for 3 mins

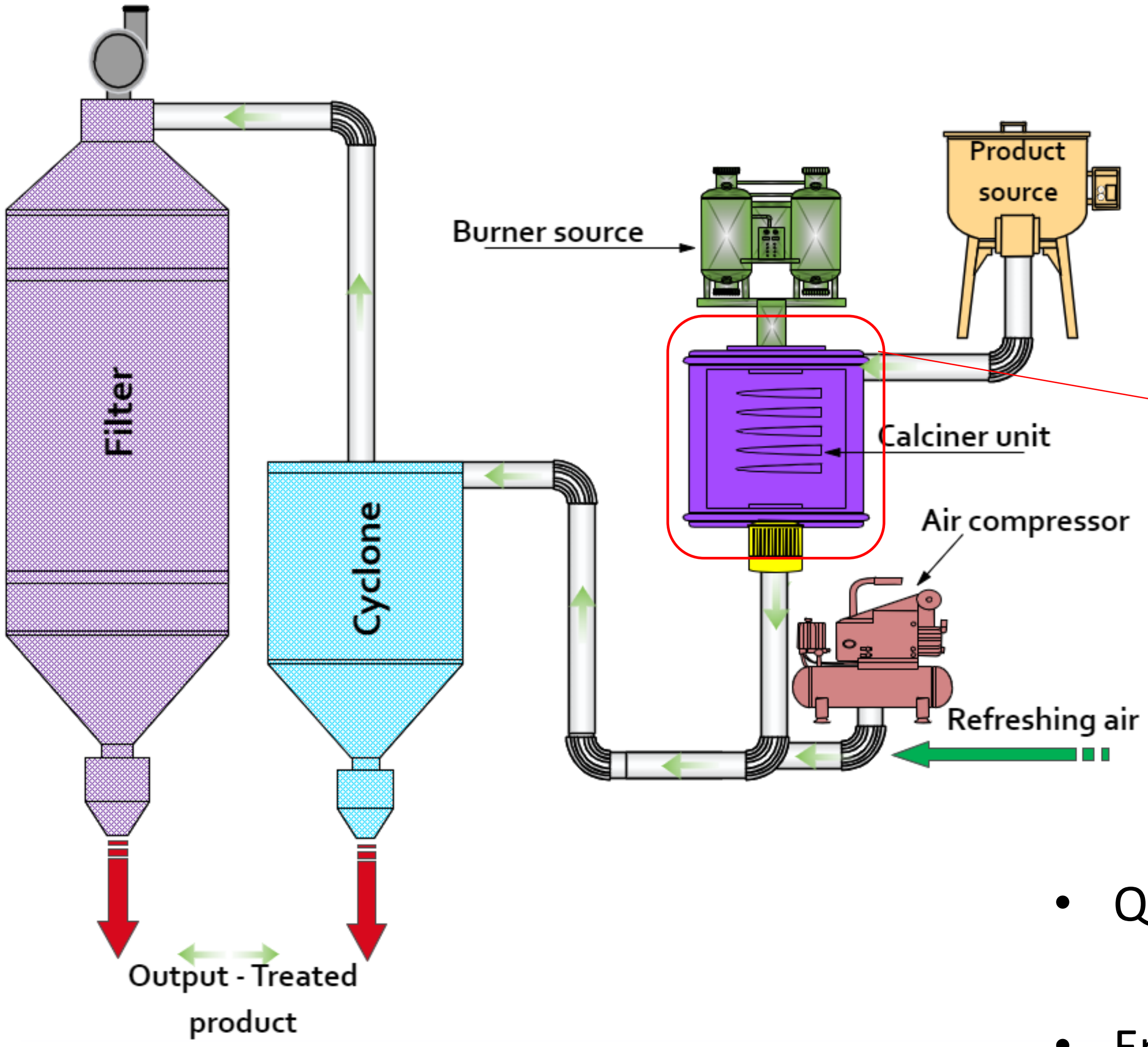
Add sand for 5 mins

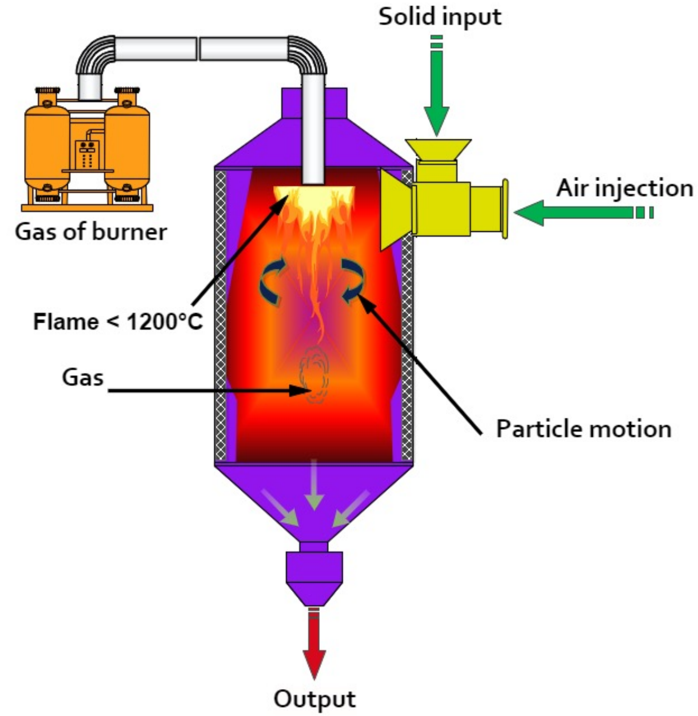
Curing

Note: *all samples needs max of 4 hours to be cured at room temp*

IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

Flash-calcination





- Quick process to activate minerals
- Environnemental and energy efficiency

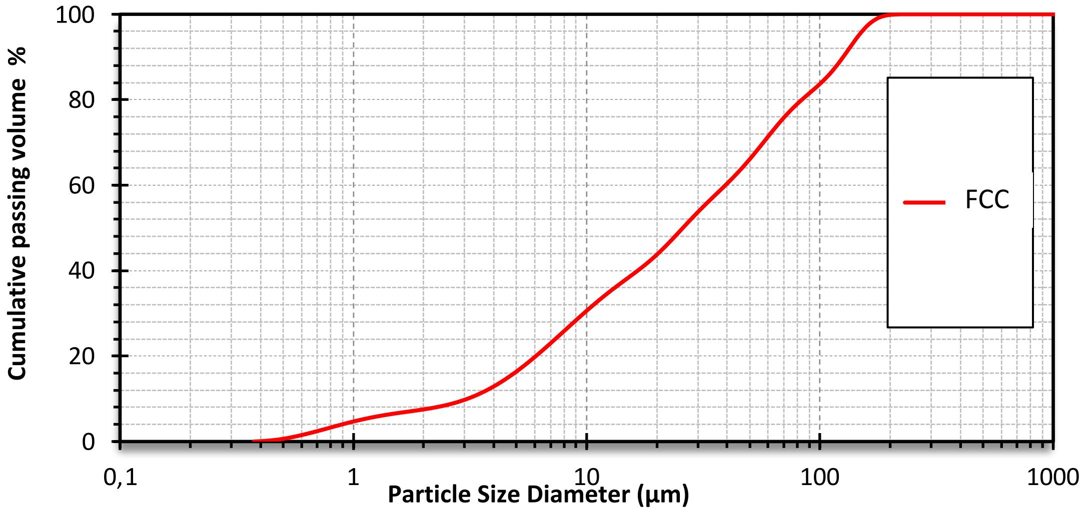
Characterization and materials properties

Flash calcined excavated earth (FCC)

(SGP)

Physical Characteristics	Millstone Clay	
	Raw	FCC
Density g/m³	2.49	2.71
BET m²/g	34.36	33.01
LOI %	8.6	0.57

Major Oxides	Millstone Clay	
	Raw	FCC
SiO_2	60.45	61.64
Al_2O_3	18.27	18.58
Fe_2O_3	6.63	6.87
CaO	2.02	2.85
MgO	0.75	0.77



IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

Characterization and materials properties

Laitiers (GGBFS)

(Ecocem ®)

Metakaolins (MK)

(Argeco ®)

Materials	Density (g/cm^3)	Absorption / Water demand (%)	Blaine / BET (cm^2/g)	Loss of Ignition (%)	Sulfur content (%)	Dmax (µm)
GGBFS	2.90	1.0	4200	1.45	0.1	20
MK	2.55	1.08	156500	1.3	0.2	80
Sand	2.65	-	-	-	0.06	2000

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
GGBFS	35.1	11.1	0.4	42.1	7.0
MK	58.1	30.8	2.9	1.2	0.2
Sand	98	-	-	-	-

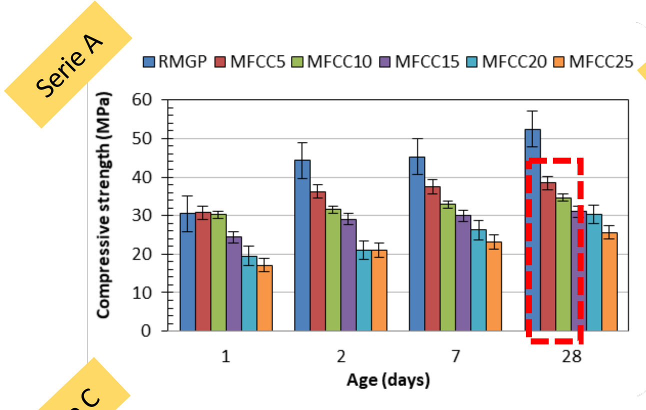
			RMGP	MFCC5	MFCC10	MFCC15	MFCC20	MFCC25
Series	SiO_2/Al_2O_3	ALK/B	0.88	0.92	0.97	1.01	1.06	1.11
		FCC	0.00%	5.00%	10.00%	15.00%	20.00%	25.00%
A	3.92	MK	57.34%	60.88%	64.41%	67.94%	71.47%	75.00%
		GGBFS	42.66%	34.12%	25.59%	17.06%	8.53%	0.00%
		ALK/B	0.95	1	1.05	1.1	0.95	
		FCC	0.00%	5.00%	10.00%	15.00%	20.00%	
B	3.75	MK	64.42%	68.31%	72.21%	76.10%	80.00%	
		GGBS	35.58%	26.69%	17.79%	8.90%	0.00%	
		ALK/B	1.03	1.08	1.14	1.19		
		FCC	0.00%	5.00%	10.00%	15.00%		
C	3.59	MK	72.12%	76.41%	80.71%	85.00%		
		GGBFS	27.88%	18.59%	9.29%	0.00%		
		ALK/B	1.12	1.18	1.24			
		FCC	0.00%	5.00%	10.00%			
D	3.45	MK	80.55%	85.27%	90.00%			
		GGBFS	19.45%	9.73%	0.00%			
		ALK/B	1.22	1.28				
		FCC	0.00%	5.00%				
E	3.31	MK	89.80%	95.00%				
		GGBFS	10.20%	0.00%				

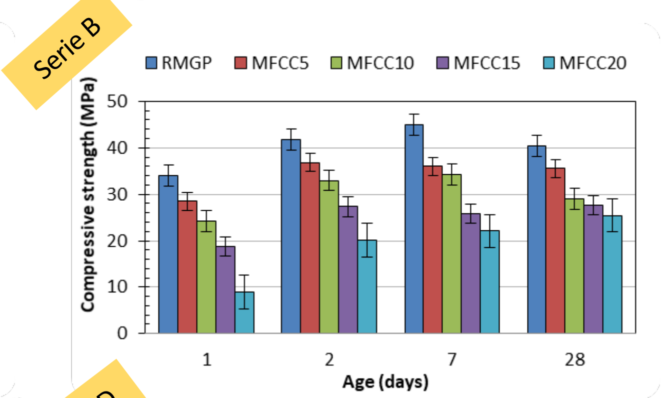
Mortar formulations

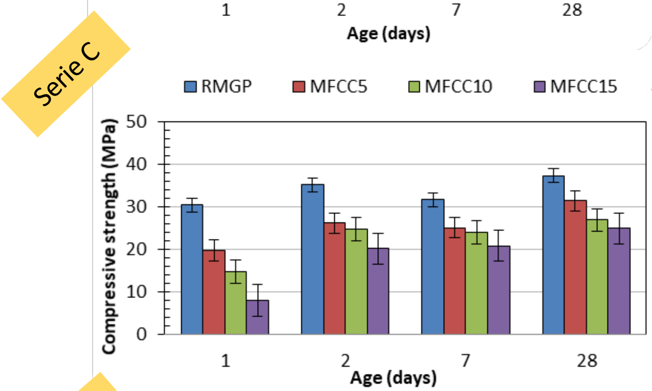
- Over 24 geopolymer formulations prepared and characterized
- Includes :
  - # SiO_2/Al_2O_3,
  - # ALK/B,
  - # % of MK, GGBFS, FCC
- SiO_2/Al_2O_3 is theorical value

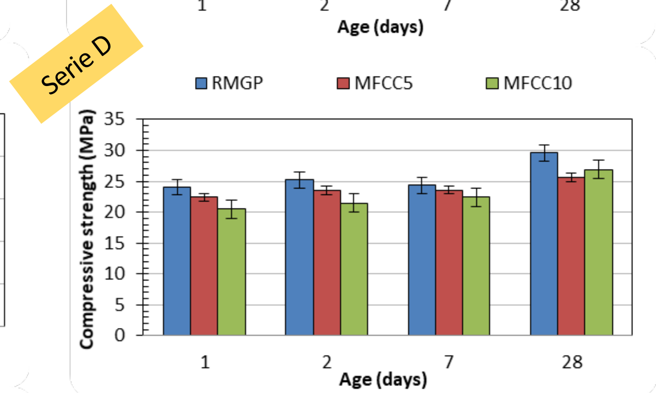
Mortar characterization : compressive test

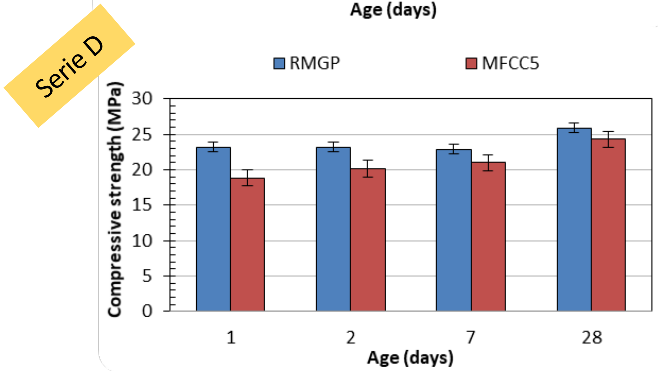
- Strength increases over time
- Strength increases over GGBFS content
- SiO_2/Al_2O_3 played a minor role as it is theorically set the best value for a given formulation







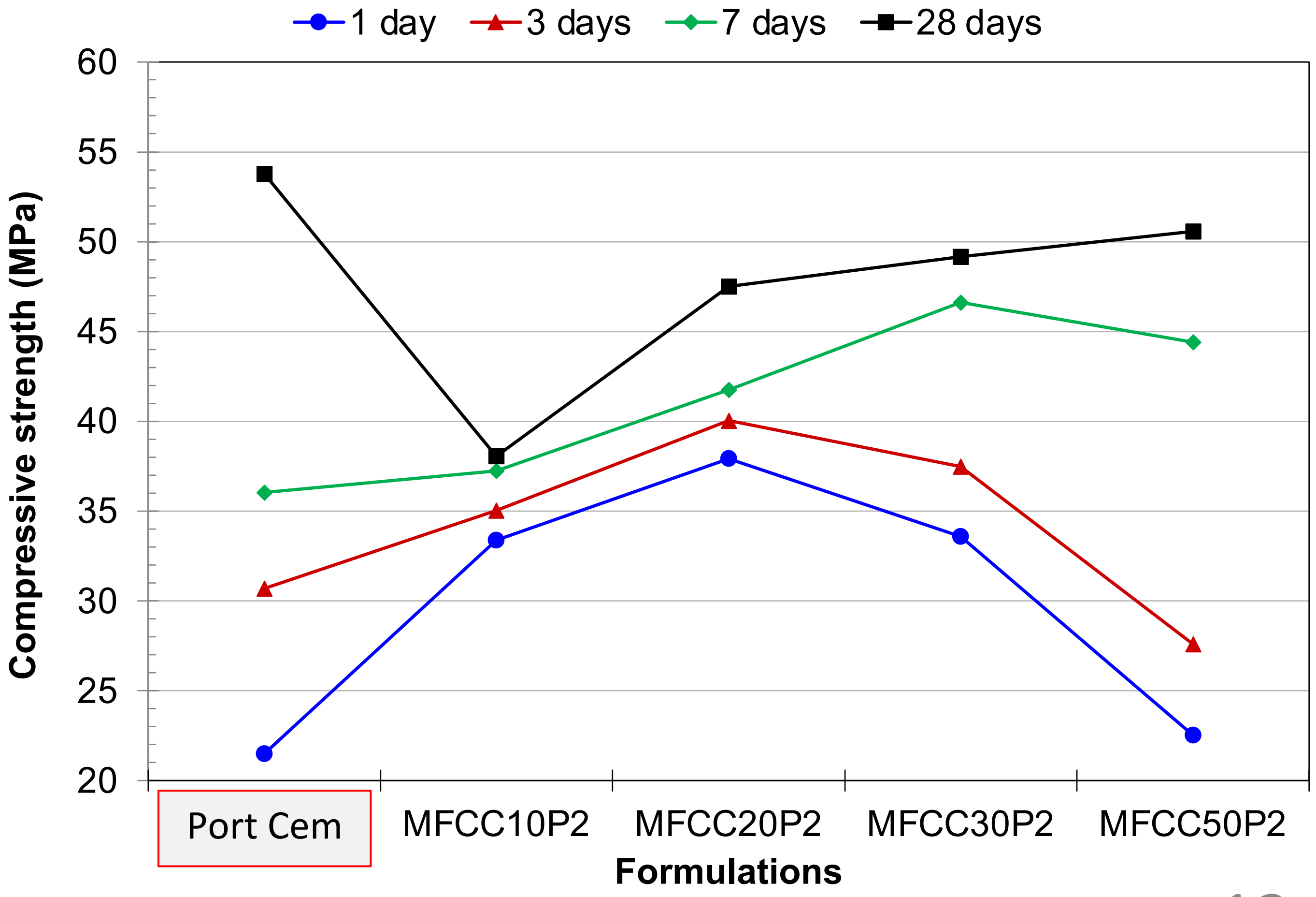




Optimized fromulations

	MFCC10P2	MFCC20P2	MFCC30P2	MFCC50P2
SiO_2/Al_2O_3	4.03	4.51	5.12	6.97
ALK/B	0.87	0.76	0.65	0.43
Tap water	-	-	-	3.6%
FCC	10.00%	20.00%	30.00%	50.00%
MK	60.00%	50.00%	40.00%	20.00%
GGBFS	30.00%	30.00%	30.00%	30.00%

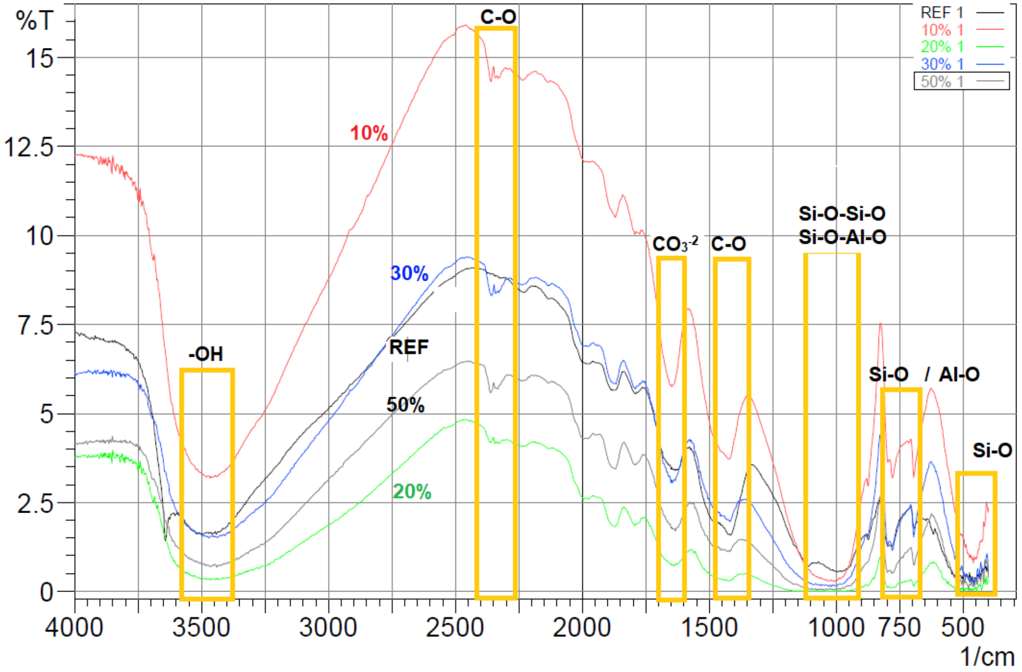
Fiber reinforced



- Strength increases when ALK/B ratio decreases
- Consistency decreases when ALK/B ratio decreases
- 30% GGBFS seems to be a good deal (performances)

IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

FTIR and Mercury porosity



	Mean pores diameter (4V/A) (nm)	Total intrusion volume (ml/g)	Total pores surface (m²/g)	Total porosity (%)
RMPC (Port Cem)	58.05	0.066	4.571	14.05
RMGP	34.54	0.0355	4.109	8.06
MFCC10P2	18.62	0.0296	6.358	6.92
MFCC20P2	18.15	0.0334	7.369	7.70
MFCC30P2	18.70	0.0346	7.405	7.99
MFCC50P2	18.10	0.0340	7.505	7.78

- Siloxo (Si-O-Si-O) and Sialate (Si-O-Al-O) bound are identified
- Geopolymer porosity structure is better (compared to OPC matrix)
- Less porosity ⇔ Better durability

IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

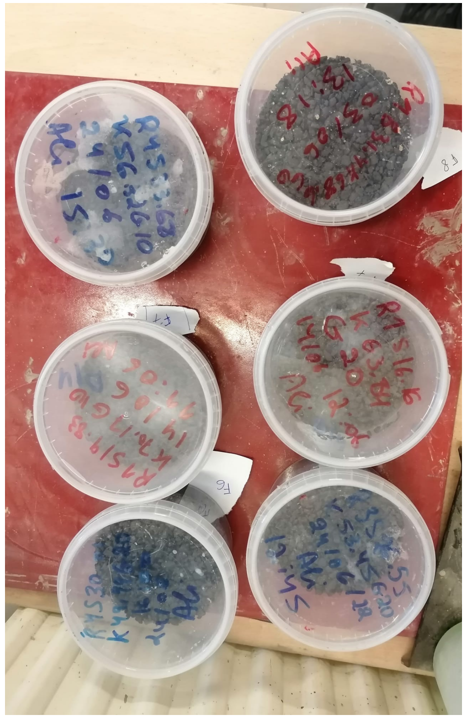
Fabrication of pervious GP concretes

Chair CIRVAL

Weighing

Mixing

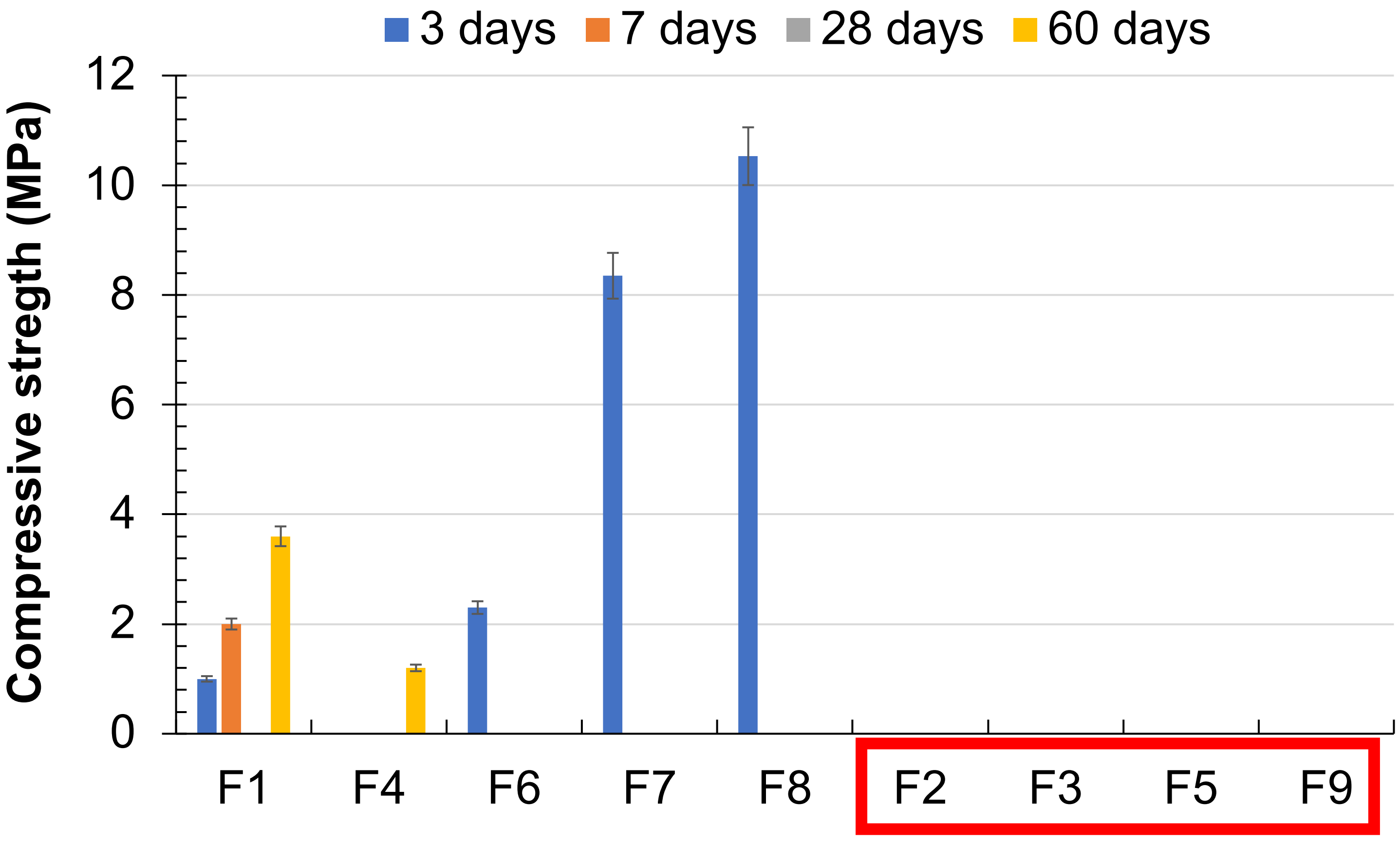
Curing/Maturation



IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

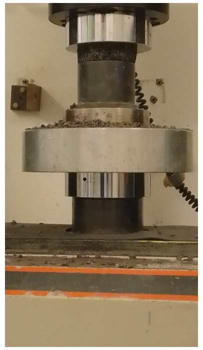
Pervious GP concrete : Compressive strength

Formulations	Constituants	Propriétés
F1	GS1	Delayed setting
F2	GS1 + random Slags	Good setting
F3	GS2	Delayed setting
F4	GS2 + Slags 5%	Good setting
F5	GS2 + Excess of Slags (ie > 10%)	Swelling
F6	GS2 + Slags 3%	Good consistency
F7	GS2 + Slags 5%	Good consistency
F8	GS2 + Slags 10%	Quick setting
F9	GS2 + Slags 15%	Stiff



Other tests :

- White aggregates-based
- Tensile strength
- Sulphate resistance
- Freeze and Thaw
- etc.



Development of GP bricks and concretes : Ongoing tests

1

2

- Reinforced Concrete formulations
- Durability testing
- GP microstructure

https://www.mecoconcept.com/en/home/

IMT Nord Europe
École Mines-Télécom
IMT-Université de

My world !