TAIPEI TECH
Since 1912
國立臺北科技大學
National Taipei University of Technology

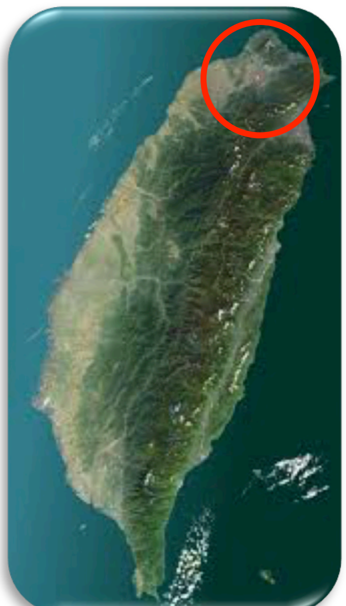
Development of Geopolymer in Taipei Tech, Taiwan

Institute of Mineral Resources Engineering
National Taipei University of Technology

Wei-Hao Lee (Jacky)

Mineral Processing Laboratory

National Taipei University of Technology (Taipei Tech)



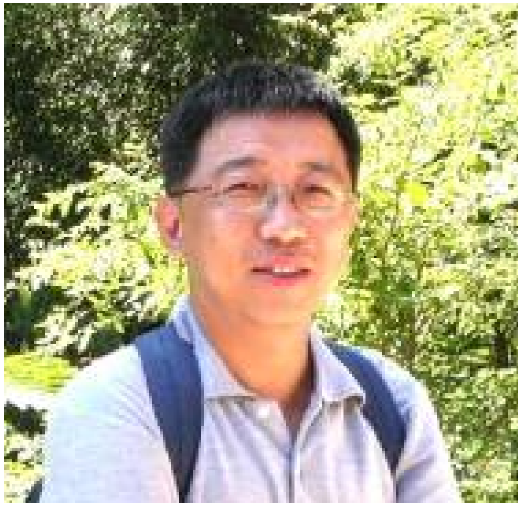
Taiwan

Taipei

Taipei Tech

Institute of Mineral Resources Engineering
Mineral Processing Laboratory

Cheng, Ta-Wui



Dr. Ta-Wui Cheng

Professor

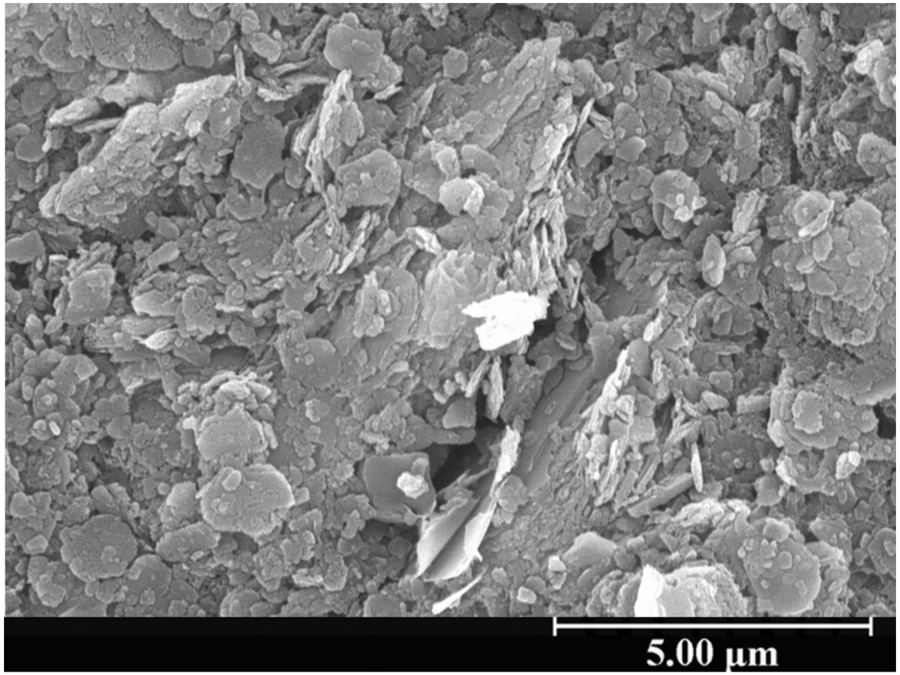
Research Topics

Mineral Processing Engineering
Recycling
Powder Technology
Mineral materials and Functional Composites

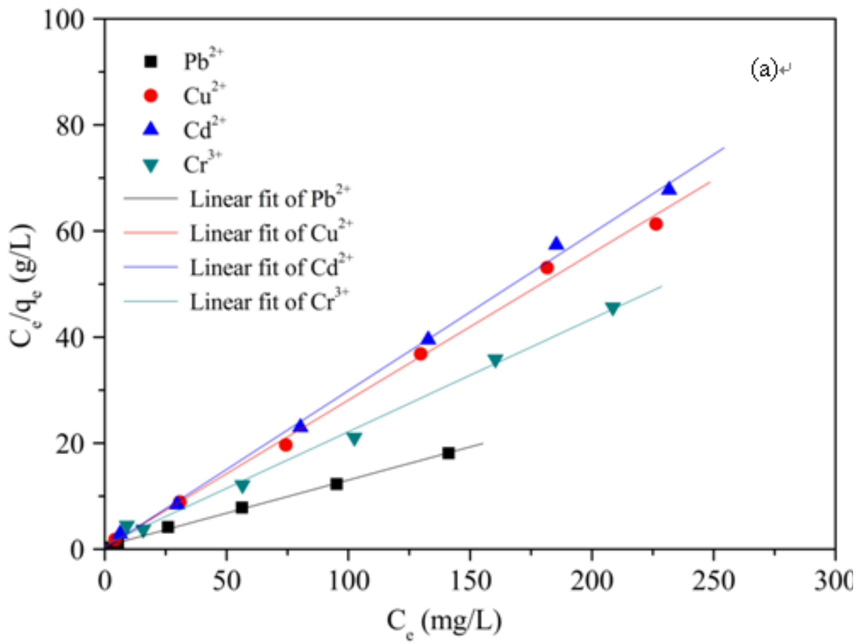
Education Information

Ph.D. University of New South Wales, Australia
M.Sc. University of New South Wales, Australia

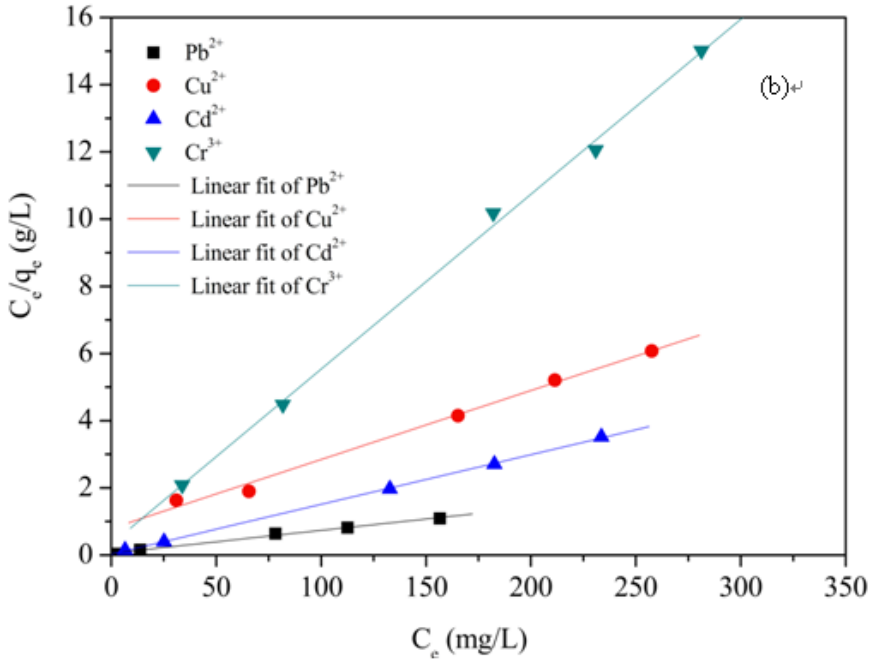
Heavy metal adsorption characteristics on metakaolin-based geopolymer



Langmuir isotherm for the adsorption of heavy metals onto geopolymer

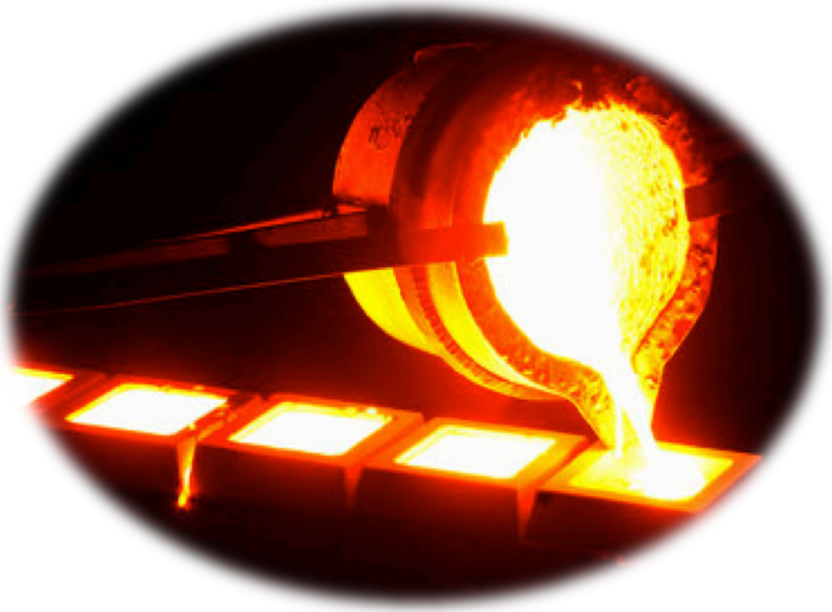


pH < 2

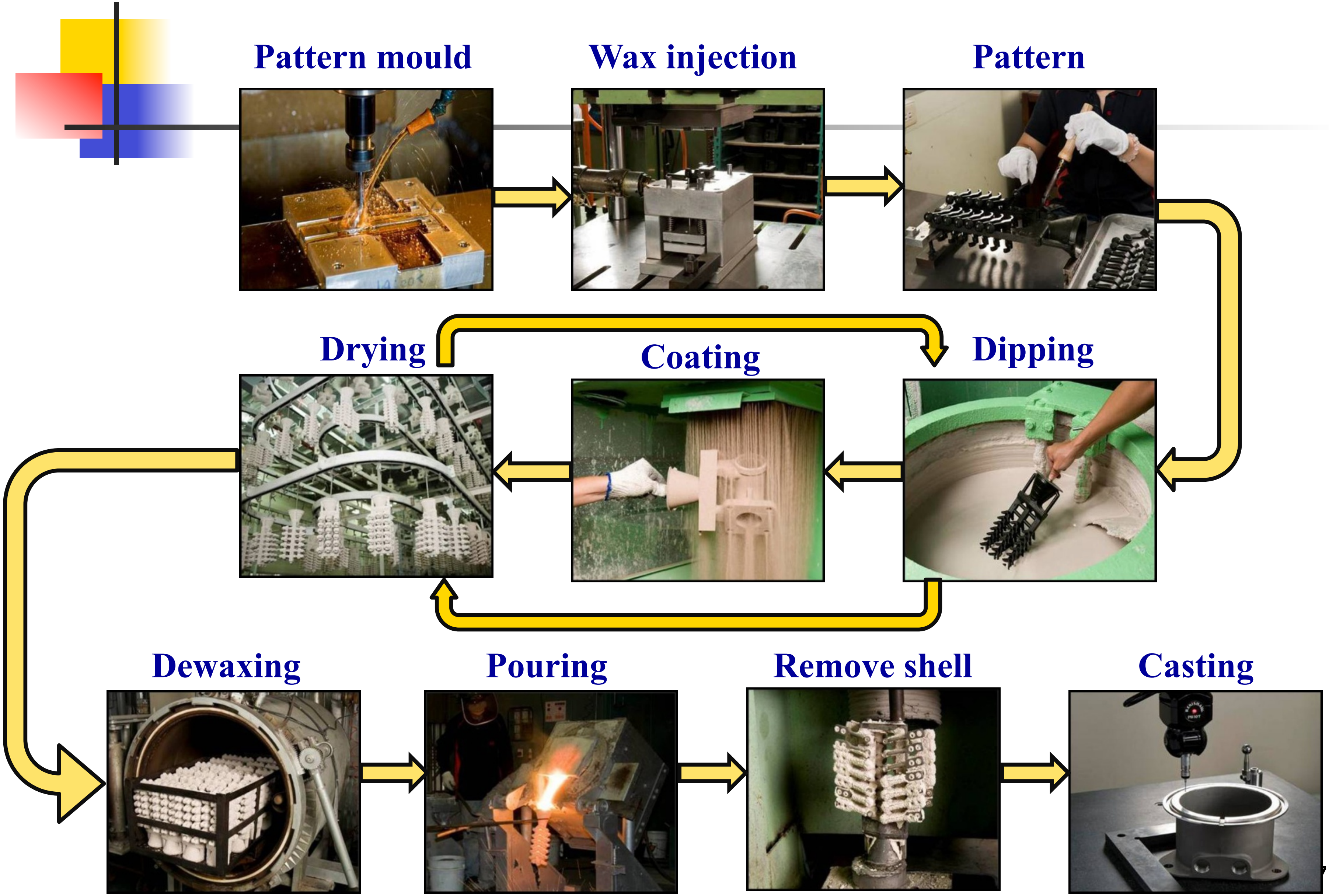


pH = 4

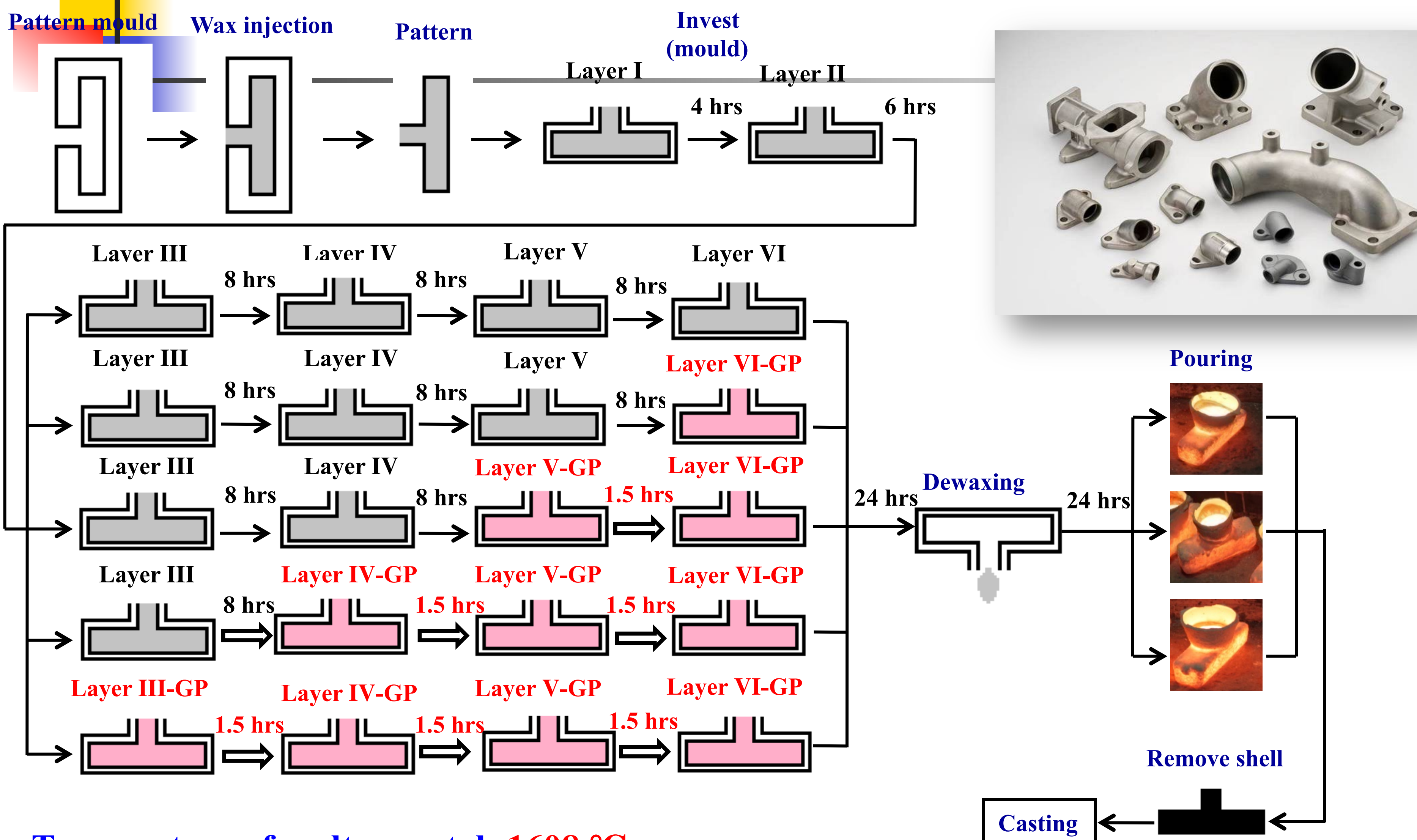
Recycled ceramic shell mould as refectory coating materials for **investment casting**



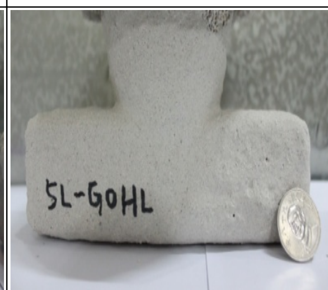
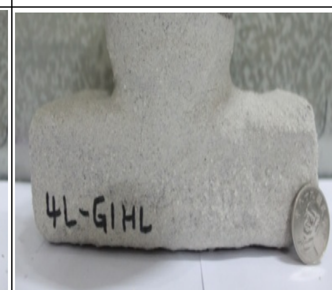
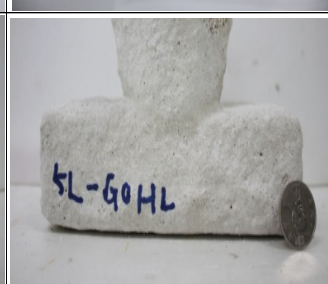
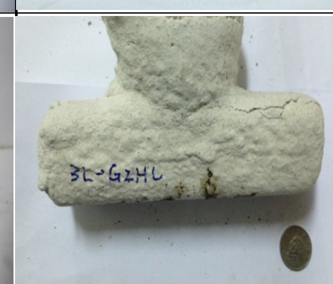
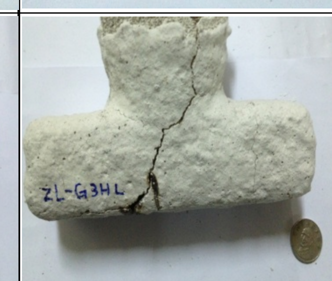
Lost wax casting



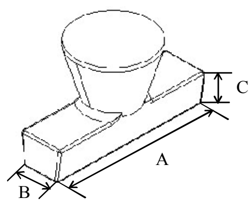
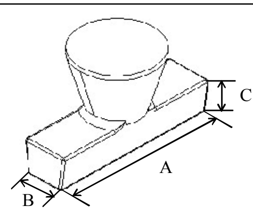
Outer layers casting mould replaced by geopolymer



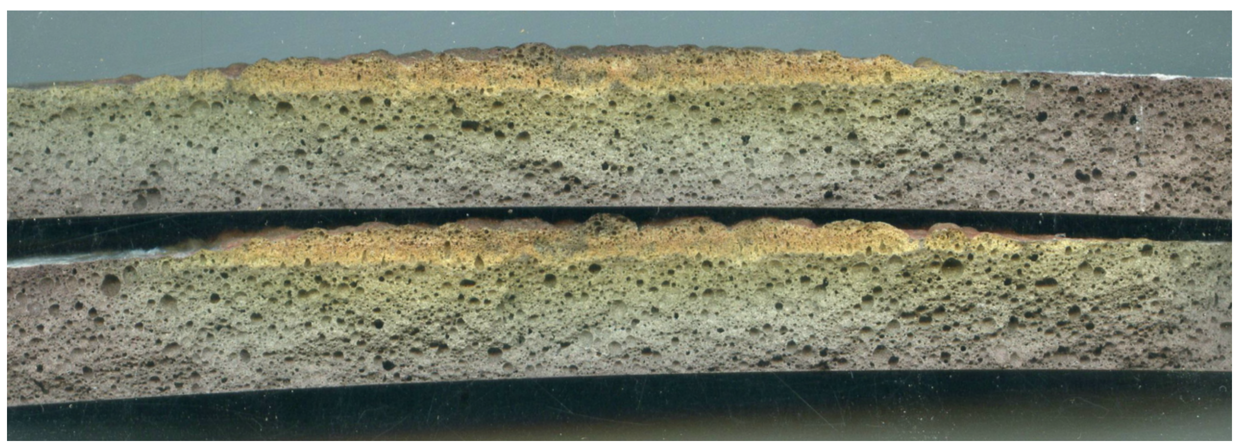
Temperature of molten metal: 1608 ℃

Shell mould					
Step	**5HL**	**5L-G0HL**	**4L-G1HL**	**3L-G2HL**	**2L-G3HL**
Before lost wax					
After lost wax					
After cast					

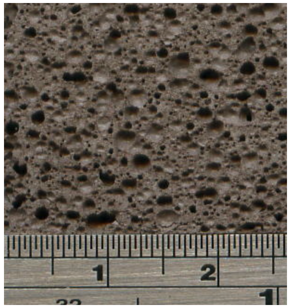
Surface and dimension change after casting

<table>
<tr><th colspan="6">Casting</th></tr>
<tr><td rowspan="2">Surface</td><td colspan="2">Diagram of casting</td><td>5HL</td><td>5L-G0HL</td><td>4L-G1HL</td></tr>
<tr><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Dimension</td><td>A</td><td>172.5±0.9 mm</td><td>172.2±0.1 mm</td><td>172.1±0.2 mm</td><td>172.2±0.1 mm</td></tr>
<tr><td>B</td><td>38.6±0.4 mm</td><td>38.7±0.1 mm</td><td>38.8±0.2 mm</td><td>38.8±0.1 mm</td></tr>
<tr><td>C</td><td>35.9±0.4 mm</td><td>35.6±0.1 mm</td><td>35.7±0.2 mm</td><td>35.7±0.2 mm</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="2">Surface</td><td colspan="2">Diagram of casting</td><td>3L-G2HL</td><td>2L-G3HL</td><td rowspan="5">–</td></tr>
<tr><td colspan="2"></td><td></td><td></td></tr>
<tr><td rowspan="3">Dimension</td><td>A</td><td>172.5±0.9 mm</td><td>172.6±0.1 mm</td><td rowspan="3">–</td></tr>
<tr><td>B</td><td>38.6±0.4 mm</td><td>38.6±0.1 mm</td></tr>
<tr><td>C</td><td>35.9±0.4 mm</td><td>35.9±0.1 mm</td></tr>
</table>

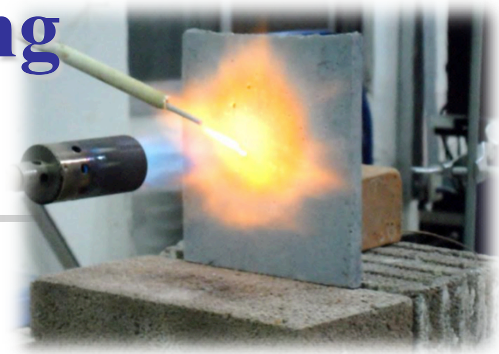
Incinerator Slag Based Foaming Geopolymer

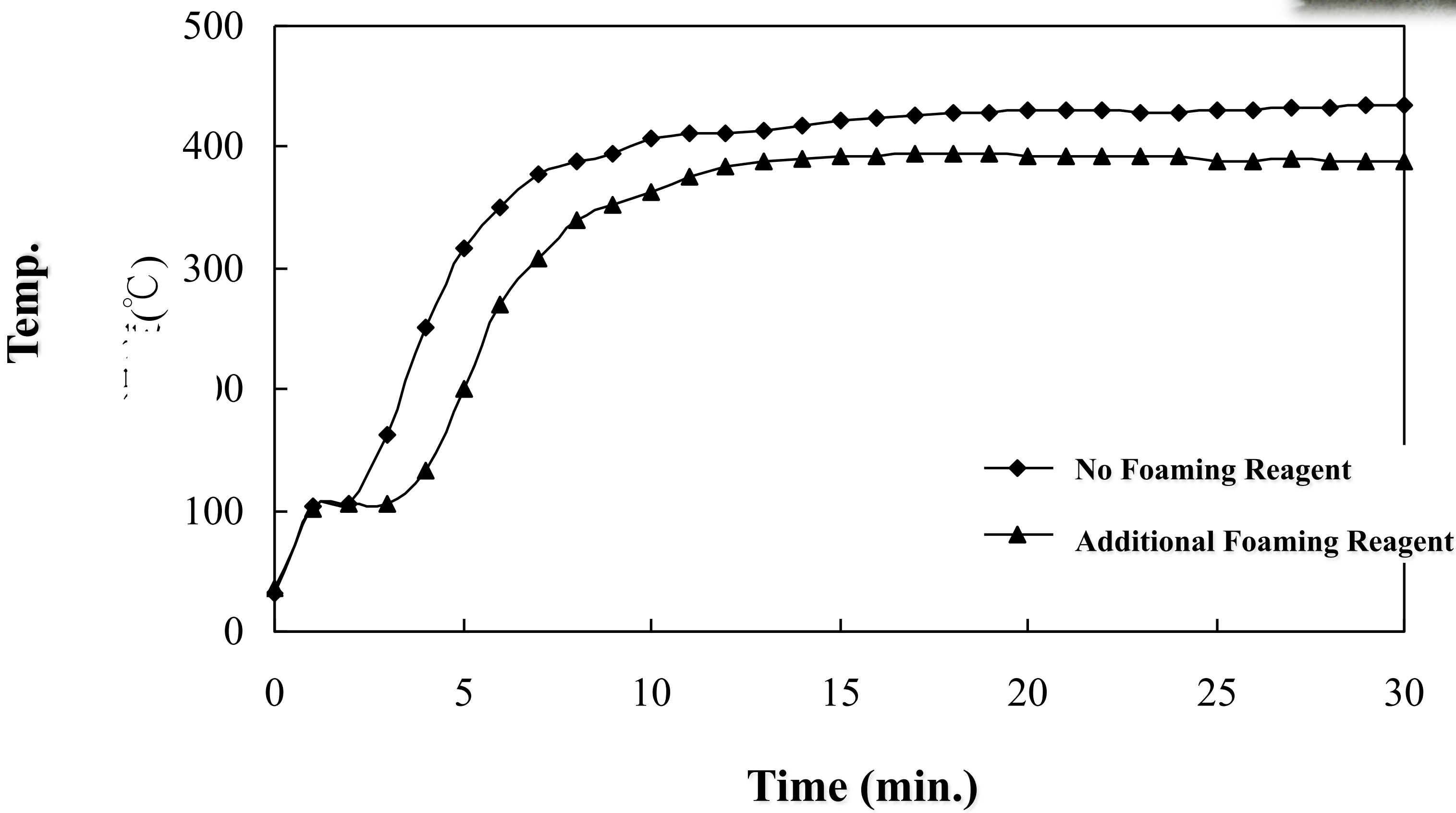


Incinerator Slag Based Foaming Geopolymer

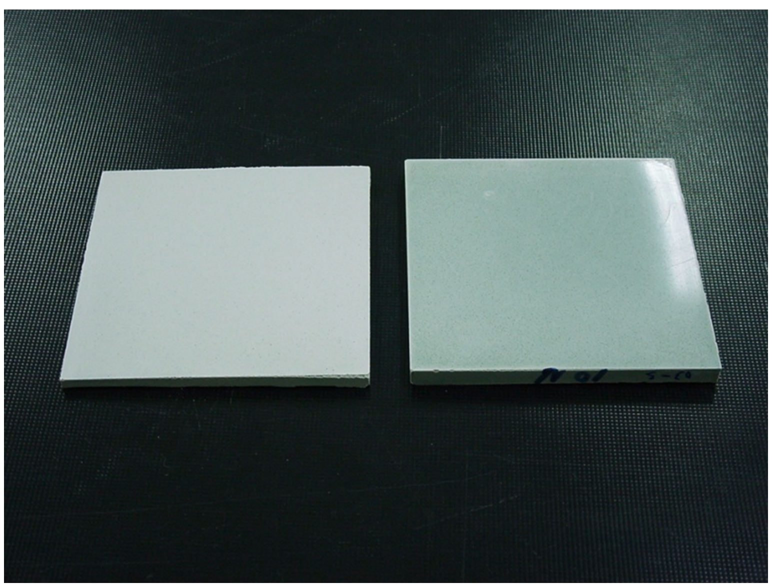
H_2O_2/Total (ml%)	Foaming Picture	H_2O_2/Total (ml%)	Foaming Picture
2%		4%	
6%		8%	

Fire Resistance Test for Foaming Geopolymer



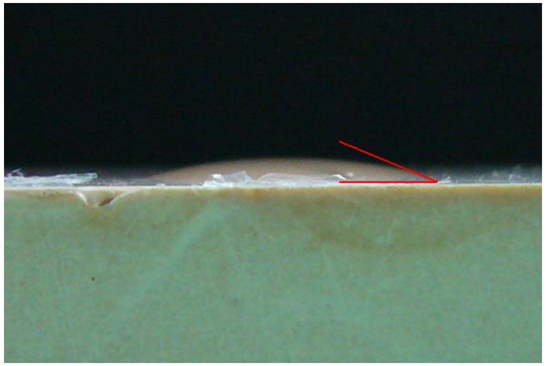


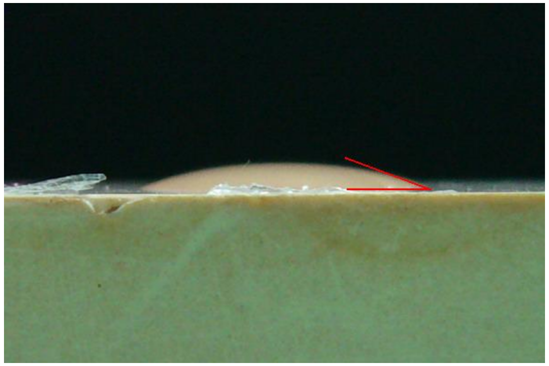
Surface Modification

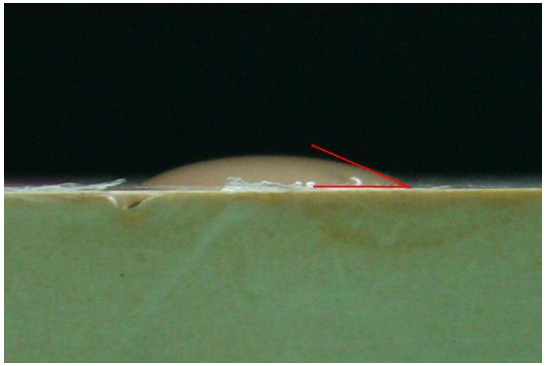


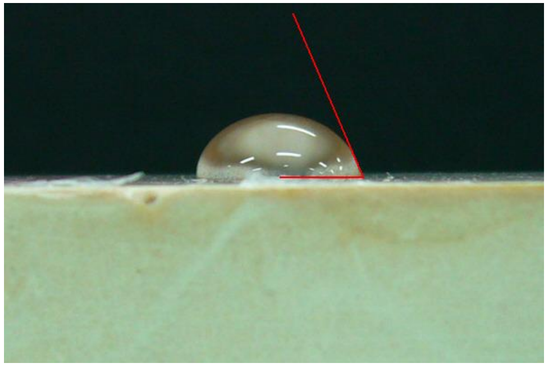
Surface Modification

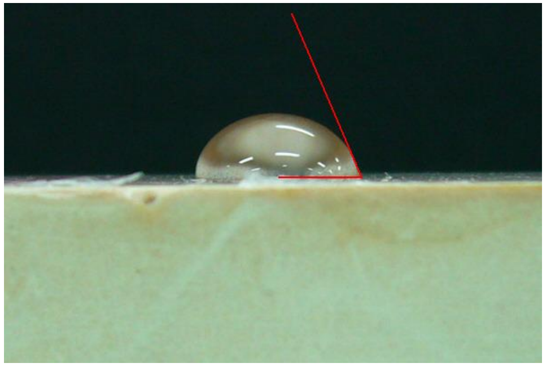
Mixing Silane and Ethanol with Volume Ratio of 1/40

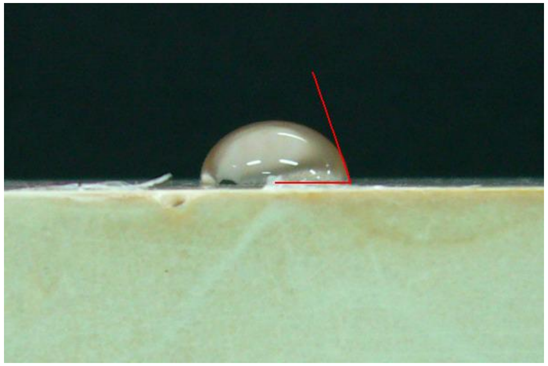

1 Layer


2 Layers

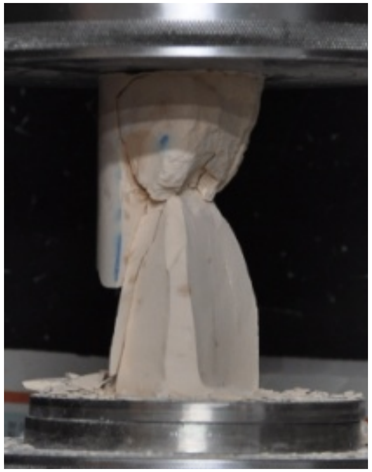
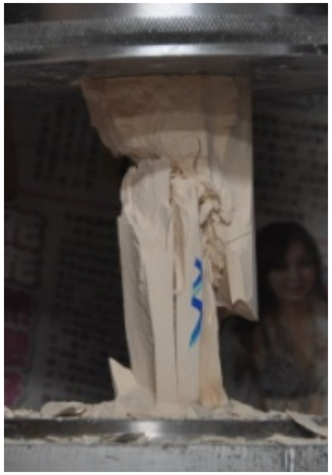

3 Layers


4 Layers

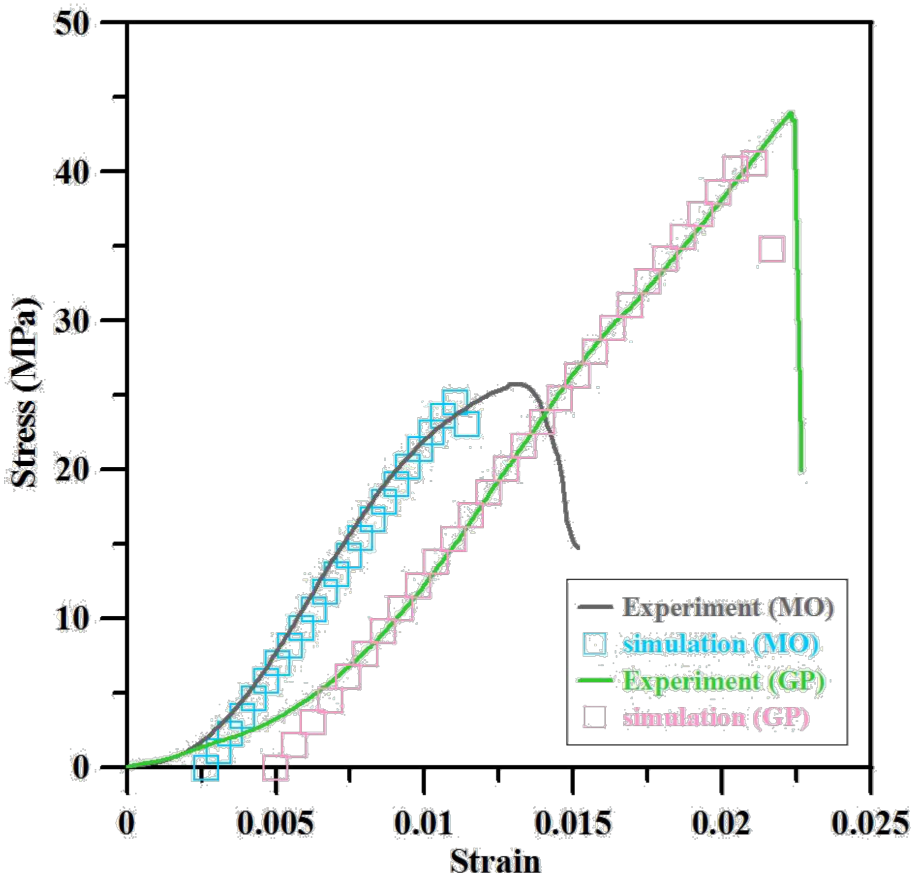

5 Layers

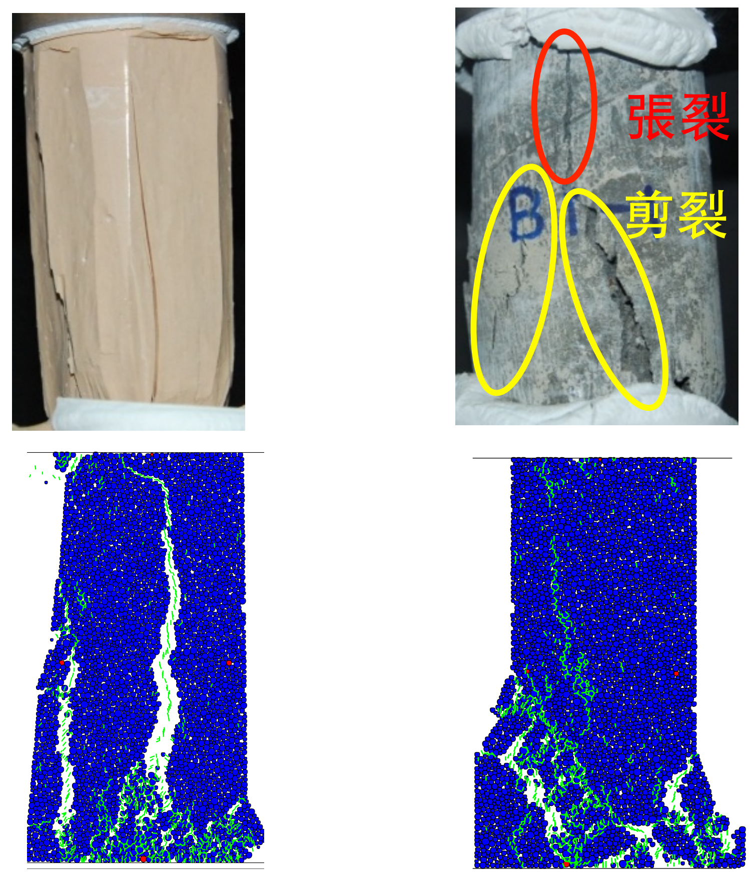

6 Layers

Study on Failure Mode

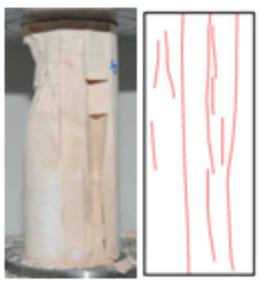
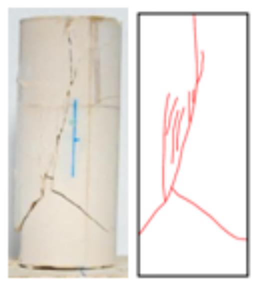
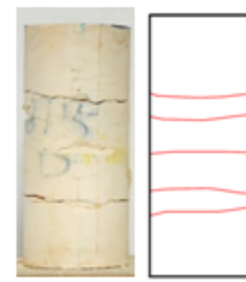
    

Individual Element Method Applied to Mode Mechanical characteristics





Mechanical properties and failure modes

Damage	Splitted	Splitted + Sheared	Monoclinic sheared	Conjugate sheared	Ductile deformed
Symbol	SP	SS	MS	CS	DD
Photo. and Depiction					

No.	SiO_2/Na_2O	σ_3			
		0	2	4	8
A	1.27	**SP**	**SP**	**SS**	**SS**
B	1.39	**SP**	**SS**	**MS**	**MS**
C	1.51	**SP**	**SS**	**MS**	**MS**
D	1.62	**SS**	**SS+MS**	**MS+CS**	**CS**
E	1.72	**SS**	**MS**	**MS+CS**	**CS**
F	1.91	**SS+CS**	**DD**	--	--

Geopolymeric Green Cement

Materials

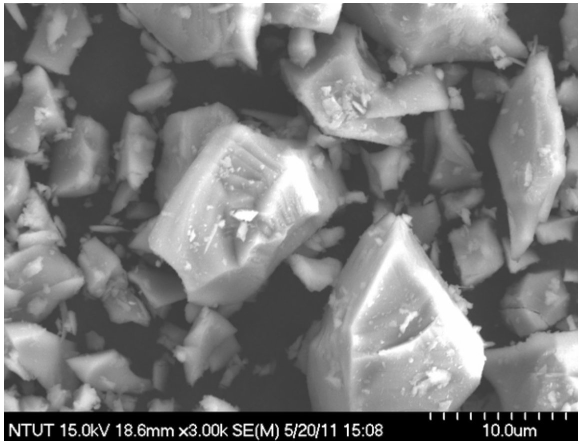
Granulated Blast Furnace Slag (GBFS) （d_{50}=12 μm）

Coal Fly Ash (CFA)（d_{50}=17.31 μm）

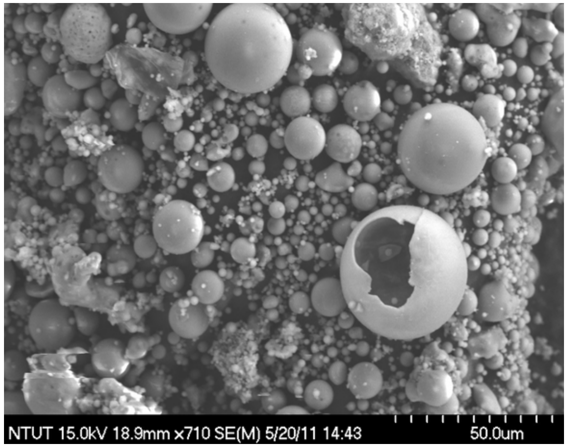
NaOH

Sodium Silicate (9.5 wt.% Na_2O、29 wt.% SiO_2)

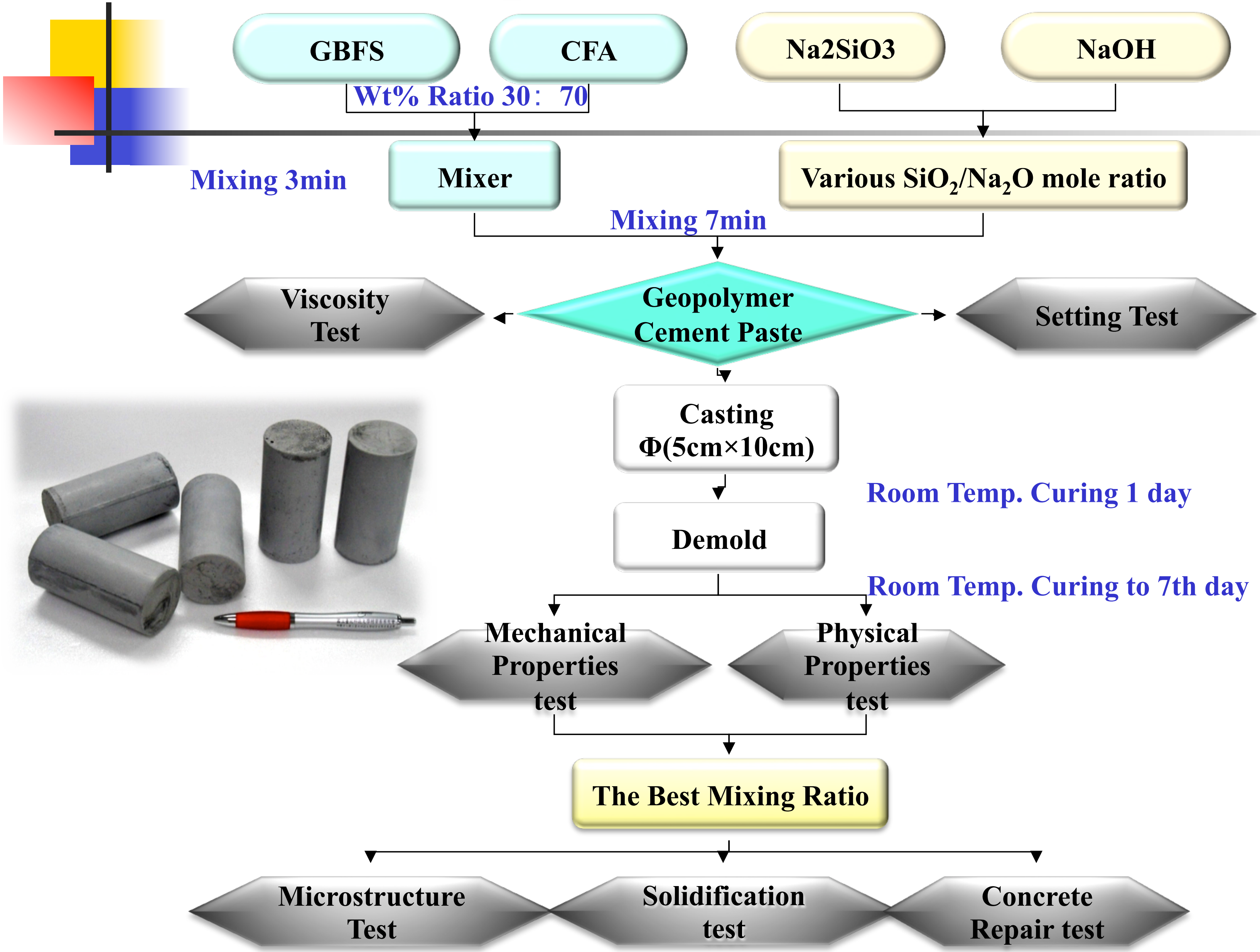
Granulated Blast Furnace Slag



Coal Fly Ash

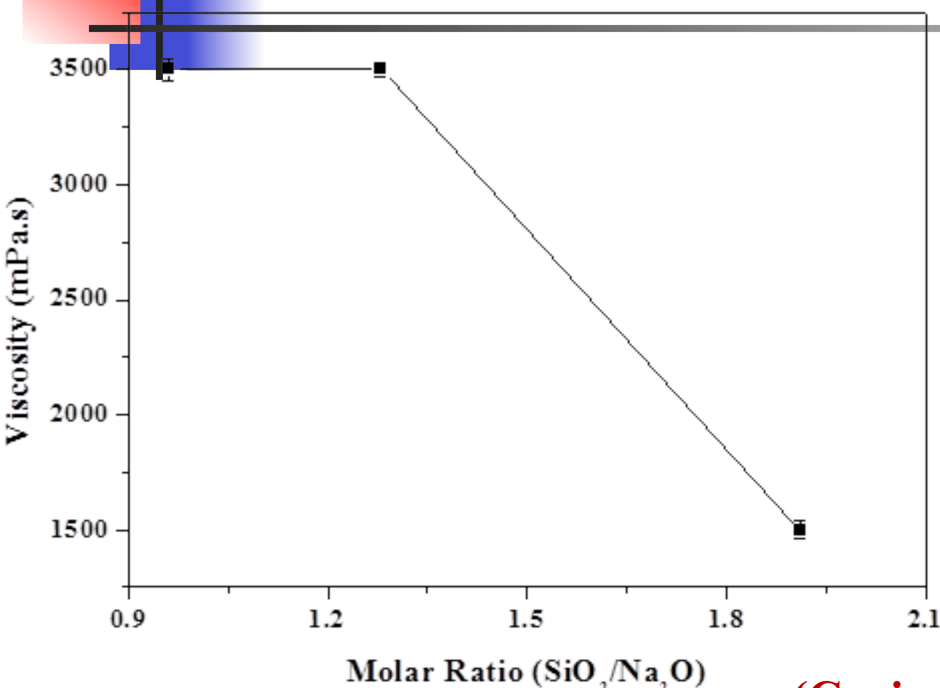


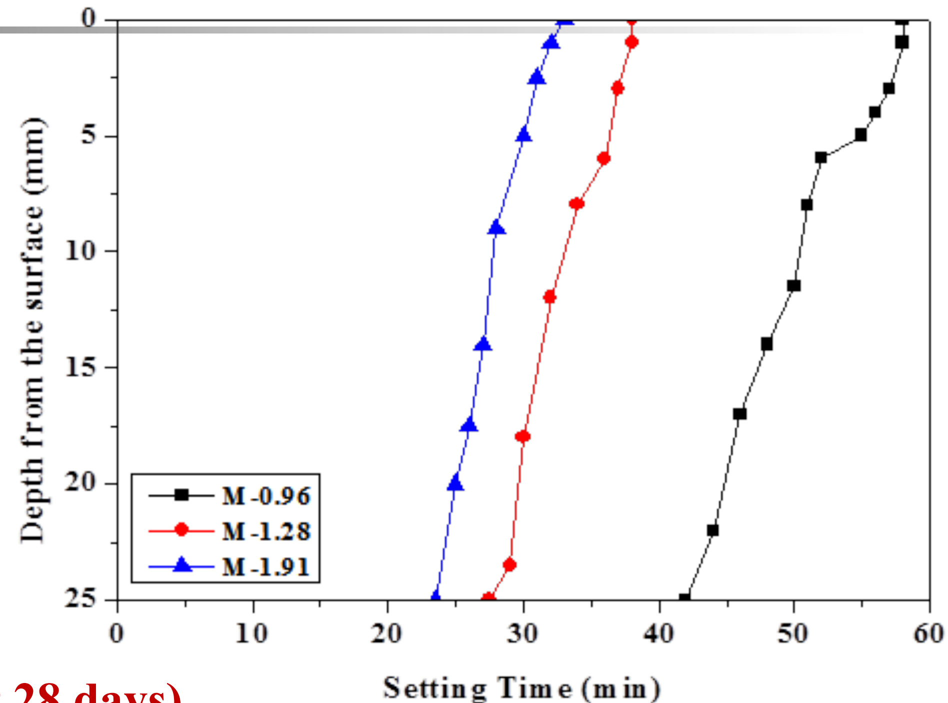
Experimental



Green Cement Physical Properties

Effect of SiO_2/Na_2O mole ratio on physical properties





(Curing 28 days)

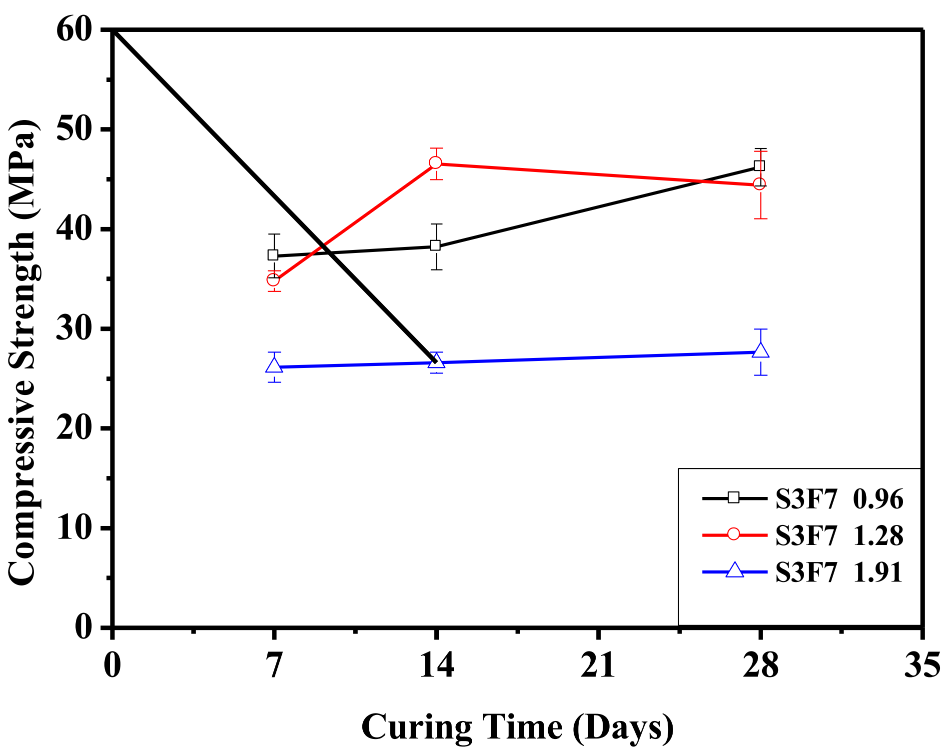
SiO_2/Na_2O Molar Ratio	Bulk Density (g/cm^3)	Apparent Specific Gravity	Porosity (%)	Water Absorption (%)
0.96	1.4±0.0	2.4±0.0	38.3±0	28.4±0
1.28	1.4±0.0	2.4±0.0	40.2±0	29.1±0
1.91	1.4±0.0	2.4±0.0	42.3±0	30.0±0

National Taipei University of Technology

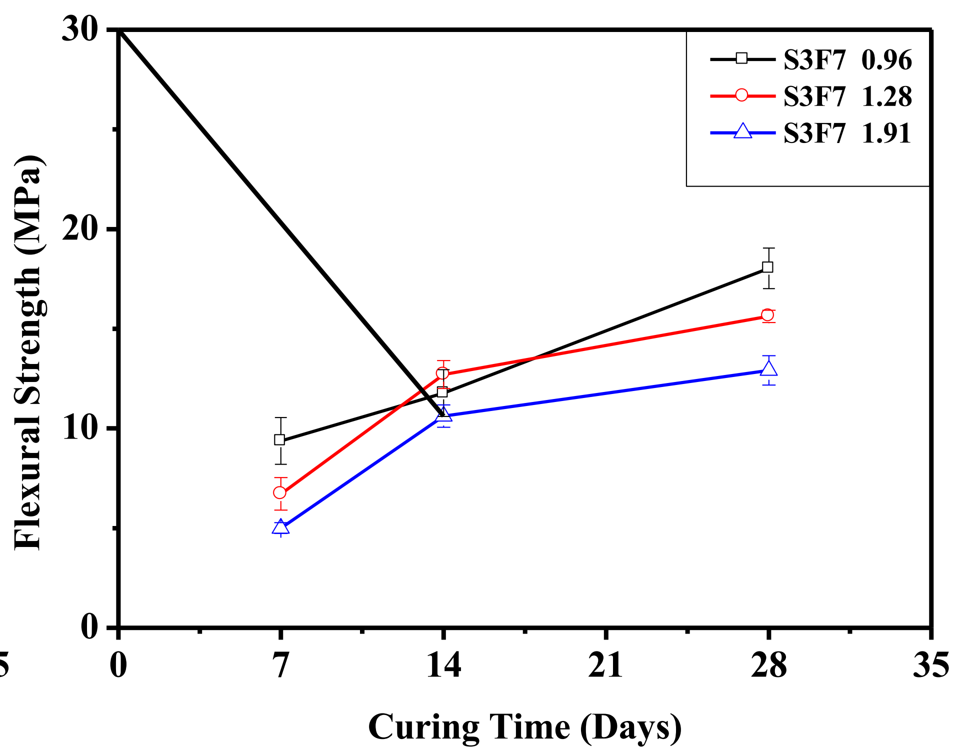
Green Cement Strength Analysis

Effect of SiO_2/Na_2O mole ratio on strength

Compressive Strength



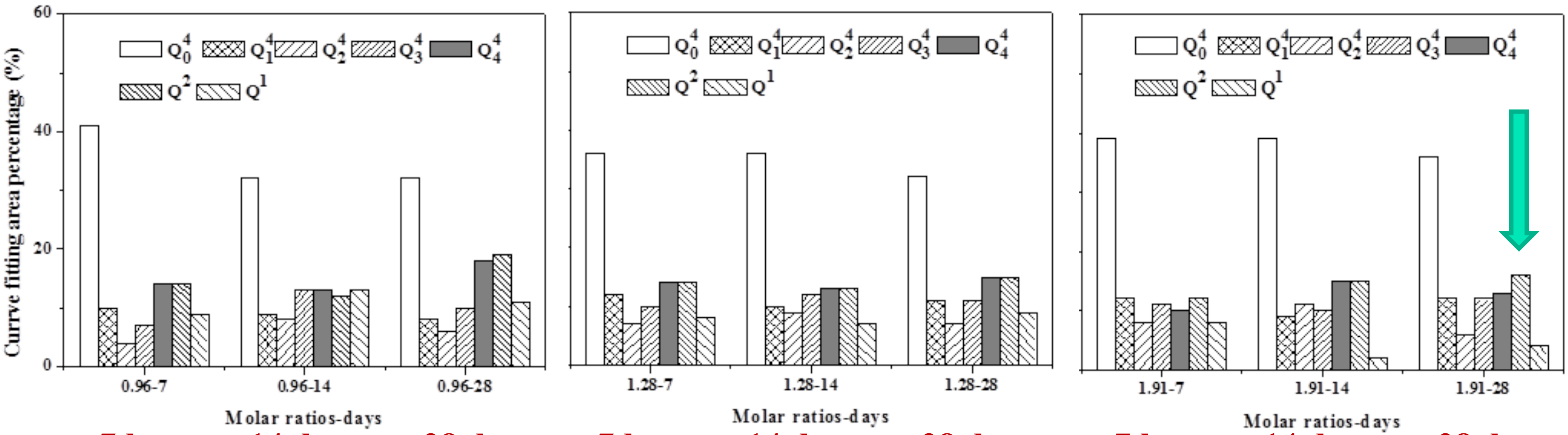
Bending Strength



Green Cement Microstructure Analysis

^{29}Si NMR Fitting Analysis

M-0.96 M-1.28 M-1.91



7days 14 days 28 days | 7days 14 days 28 days | 7days 14 days 28 days

Curing days | Curing days | Curing days

Q_4^4 Fitting Area ：M-0.96 > M-1.28 > M-1.91。

High Alkali Condition: Q_4^4 Major Structure → 3D structure

Low Alkali Condition: Q^2、Q^1 Major Structure → Line structure

Application of Geopolymeric Green Cement : Building Repair Material

Preparation of Building Repair Material

Water | OPC | Sand

Water / Cement = 0.75, 0.85

CNS 1230

Mortar

↓

Molding
(a) 10 × 10 × 25 cm
(b) 4 × 4 × 16 cm

↓

Curing in water

Curing 28 days

↓

OPC Substrate + **Geopolymeric green cement repair agent**

↓

Repair sample

Room temperature ; Curing 14, 28, 90, 180 days

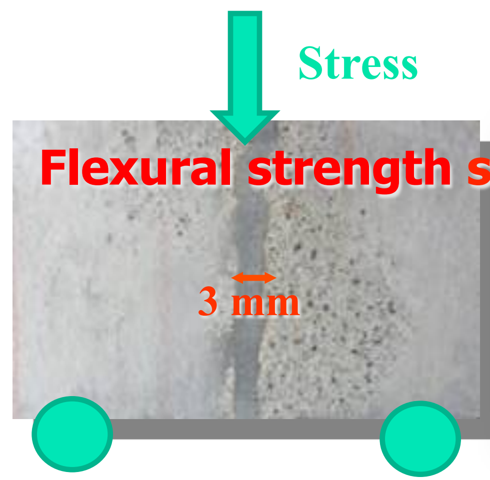
Flexural strength | Compressive strength

Geopolymeric green cement repairing agent

OPC Substrate

	Water	OPC	Sand
OPC Substrate	0.85	1	2.75
	0.75	1	2.75
Compressive strength sample	Dip angles (β)		
	40°	50°	60°
	Crack Width		
	20 mm		
Flexural strength sample	Crack Width		
	3 mm		

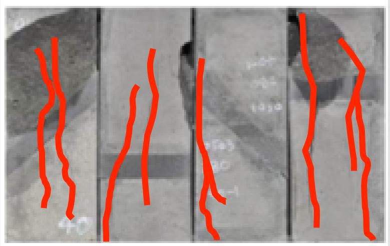
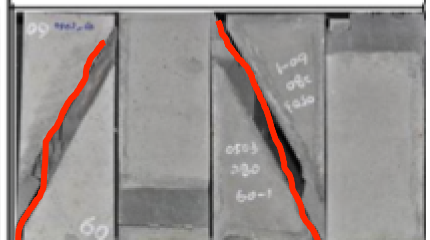
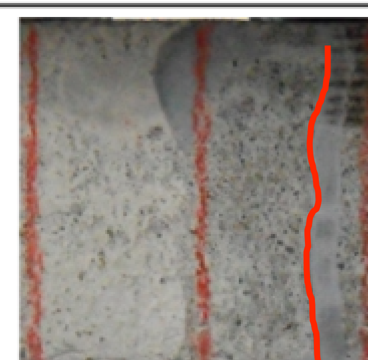
Smooth surface



Rough surface

Failure Mode

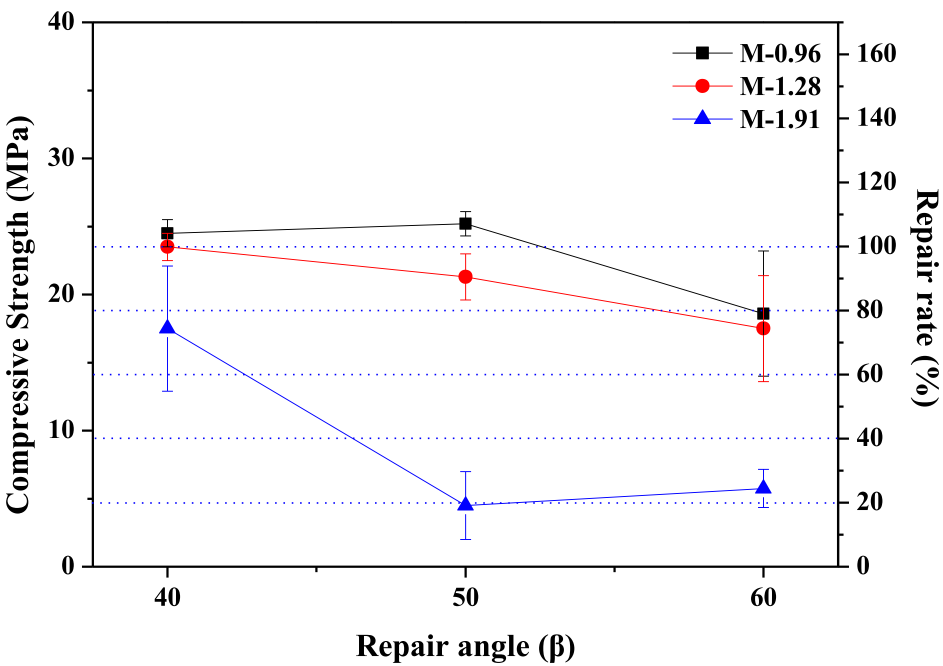
- ✓ Material Failure (MF)
- ✓ Interface Failure (IF)

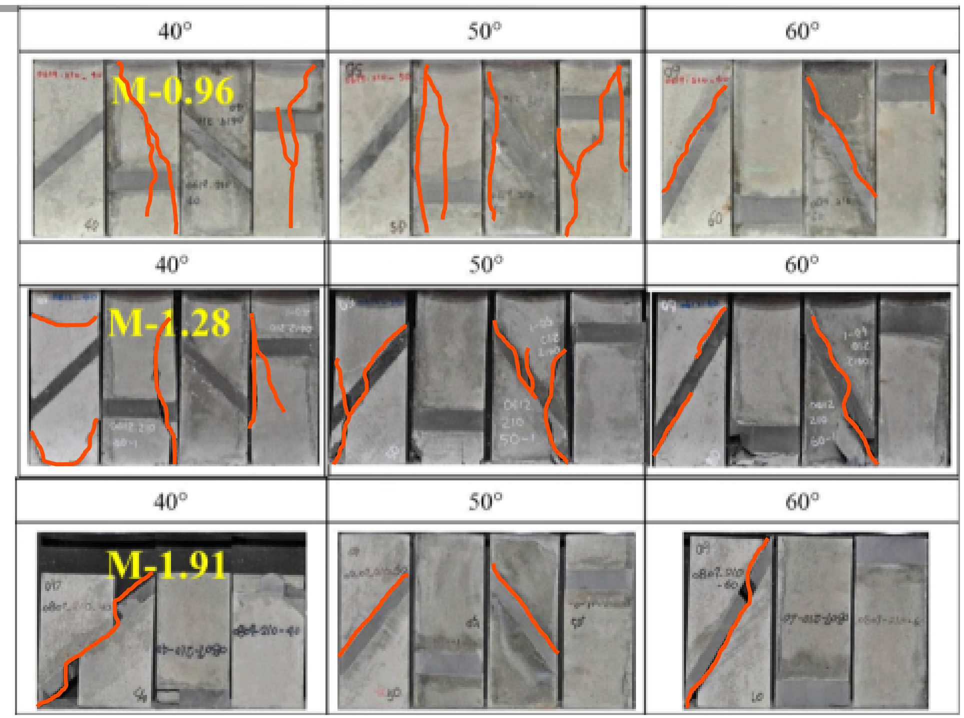
	MF		IF
Compressive strength sample			
Flexural strength sample			

28

Repair Effectiveness (Compressive strength)

Water / OPC = 0.75 (210 kgf/cm^2)





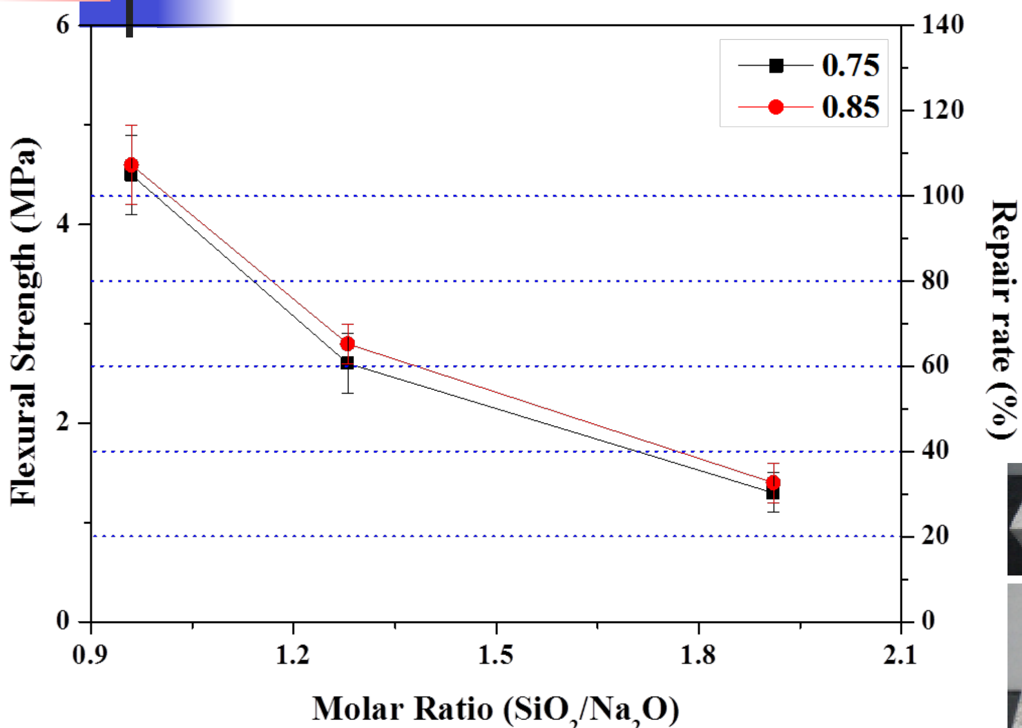
SiO_2/Na_2O molar ratio = 0.96、1.28. The repair rate > 100%

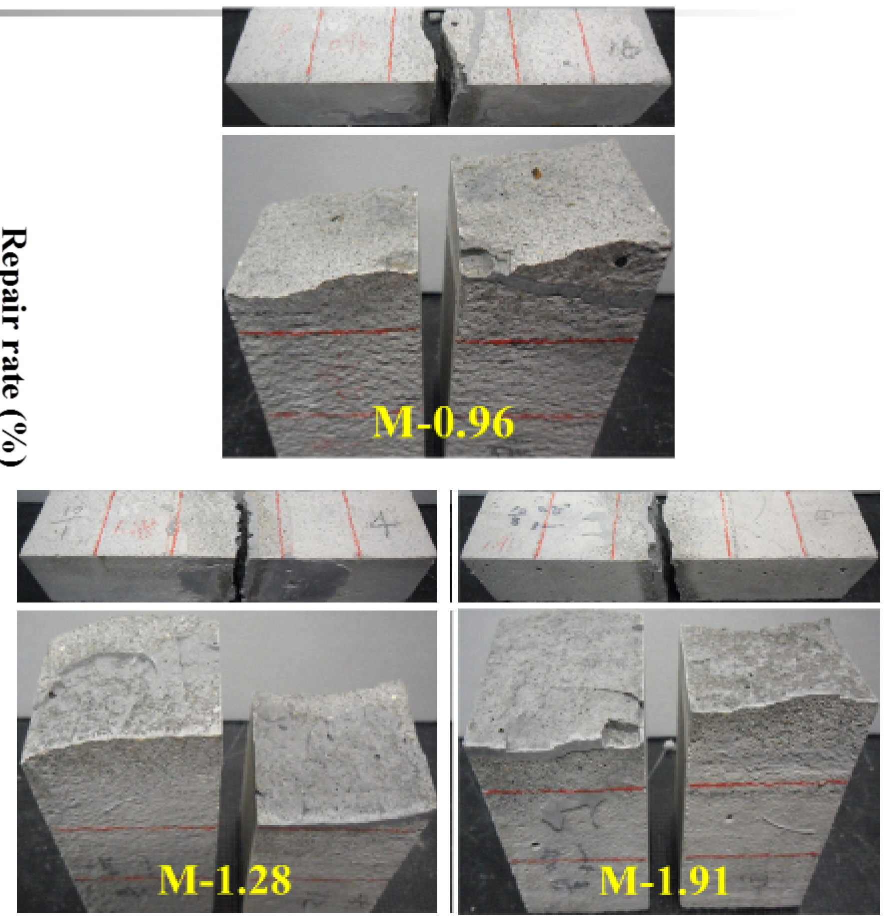
High alkaline： Material Failure (MF)

Low alkaline： Interface Failure (IF)

Repair effectiveness (Flexural strength)

SiO_2/Na_2O molar ratio = 0.96、1.28、1.91.
Water / OPC = 0.75、0.85.0





✓ **The best repair rate is 107 %**

✓ **Adhesion > Strain**

High alkaline： Material Failure (MF)

Low alkaline： Interface Failure (IF)

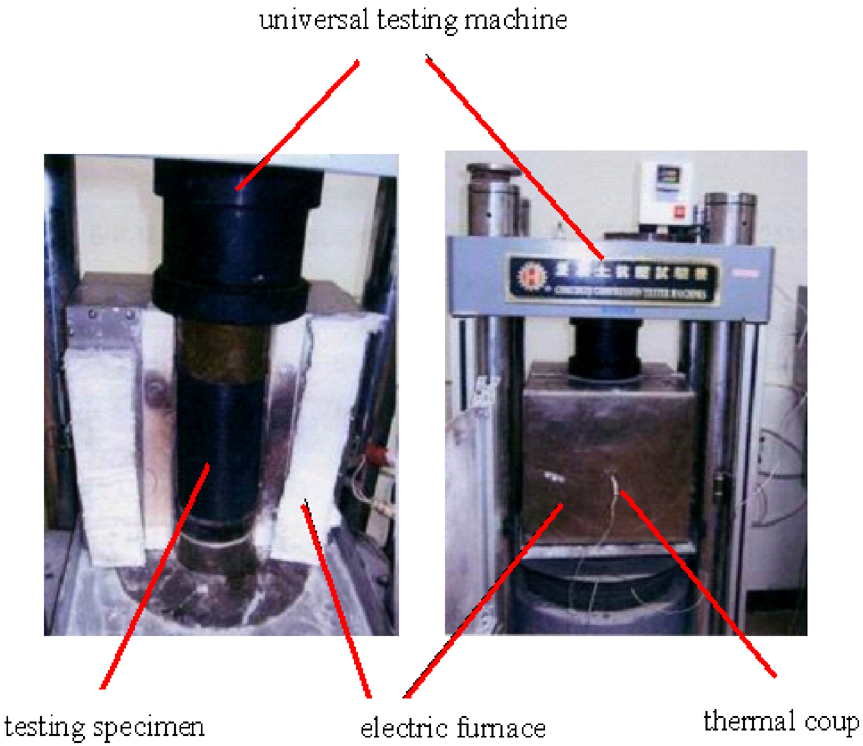
Carbon Fiber–Reinforced Polymer (CFRP) Confined Concrete

B 20cm-1層

B 20cm-2層

Uniaxial Compressive Strength Measurement of CFRP Confined Concrete

Original Concrete Strength (MPa)	Binder	Type of Carbon Fiber	Surface Treatment	Overlapping Length (mm)	One-Layer CFRP Confinement		Two-Layer CFRP Confinement		Notes
					Strength (MPa)	Increased %	Strength (MPa)	Increased %	
20.0	geopolymer	A	No	100	29.5	148	42	210	This Study
				150	27.8	139	43.6	218	
				200	29.6	148	45.0	225	
		B	No	100	34.0	170	46.9	235	
				150	34.6	173	46.5	233	
				200	36.4	182	49.2	246	
		A	UV	100	31.7	159	-	-	
				150	31.2	156	-	-	
				200	32.1	161	-	-	
		A	H_2SO_4	100	34.3	172	-	-	
				150	33.9	170	-	-	
				200	34.2	171	-	-	
23.0	Epoxy		No		56.2	245	80.4	350	Lin, 1999

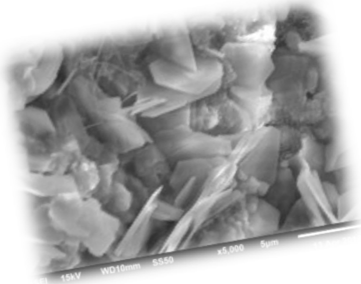


Apparatus for testing the destructive temperature

CFRP confined concrete samples before and after high temperature test

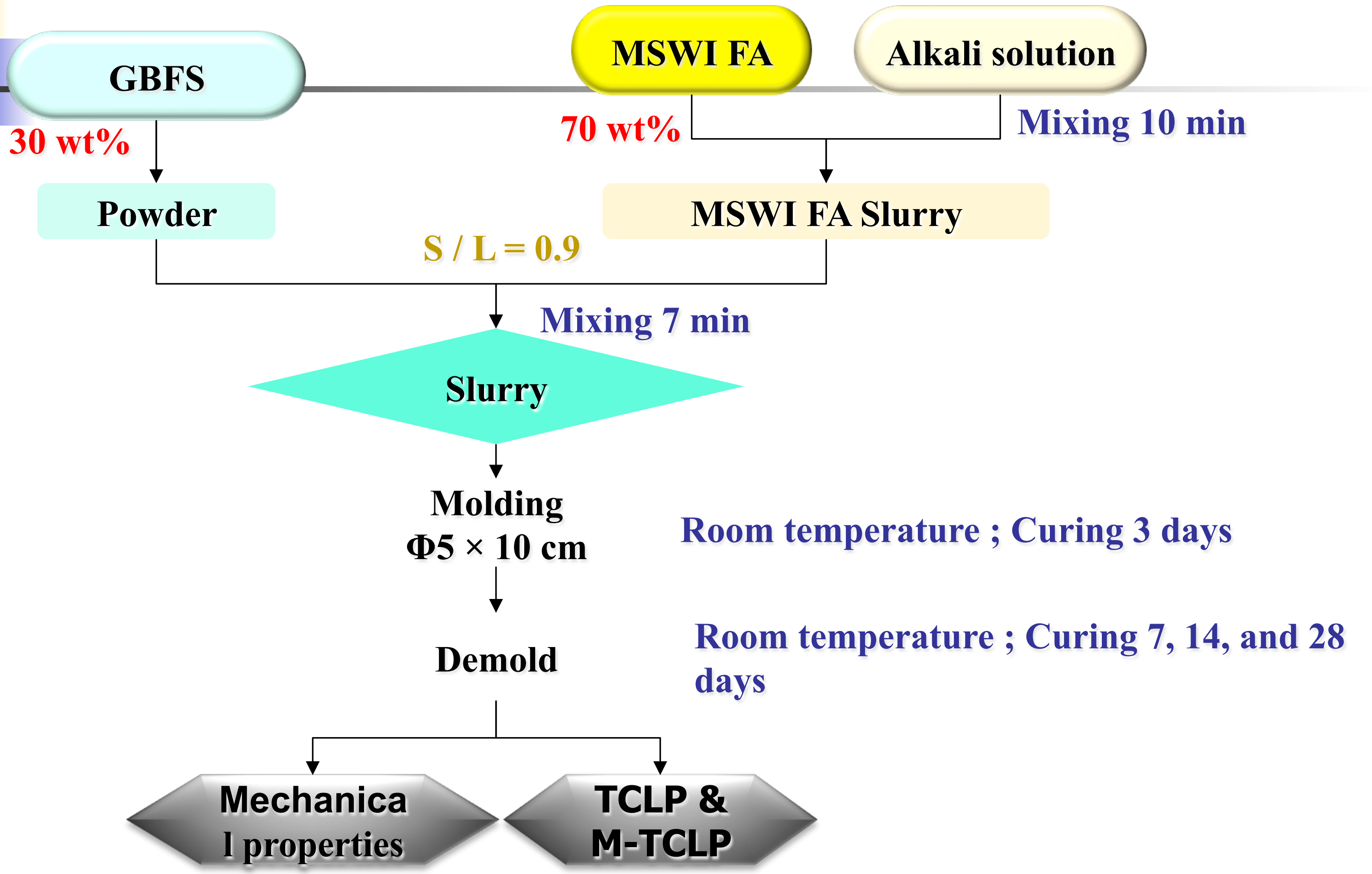
Destructive temperature of CFRP confined concrete under various loading

Original Concrete Strength (MPa)	Binder	CFRP Confinement Layer	CFRP Confined Strength (MPa)	Loading Limit (%)	Loading Pressure (MPa)	Destructive Temperature (°C)	References
13.5	Epoxy	1	38.9	35	13.5	303	Sung, 2005
				36	14.0	293	
				46	18.0	163	
				54	21.0	119	
20.0	Geopolymer		34.0	85	28.9	516	This Study



Solidification/ Stabilization of Incinerator Fly Ash by Geopolymer Technology

Experimental for Immobilization Cl^- & Heavy Metals

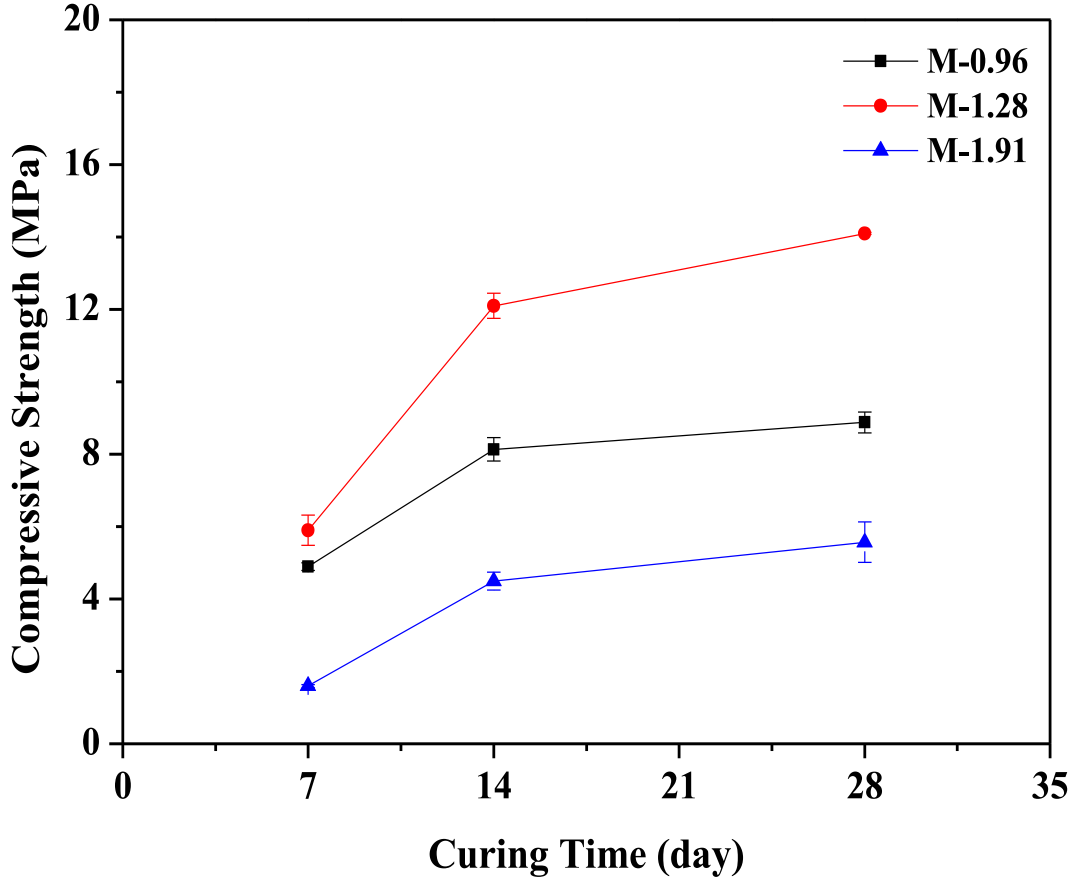


TCLP Leaching Tests

Elements	MSWI FA	7days SiO_2/Na_2O			14 days SiO_2/Na_2O			28 days SiO_2/Na_2O			Standard value
		0.96	1.28	1.91	0.96	1.28	1.91	0.96	1.28	1.91	
Ba	3.6	0.2	0.7	0.4	0.2	1.0	0.5	N.D	N.D	N.D	100
Zn	21.3	N.D	1.18	N.D	N.D	N.D	N.D	N.D	N.D	N.D	-
Pb	60.2	N.D									5
Cd	N.D	N.D									1
Cr	N.D	N.D									5
Cu	≤ 0.1	N.D									15
	N.D：non detected.							Unit：mg/L			

Compressive Strength Tests

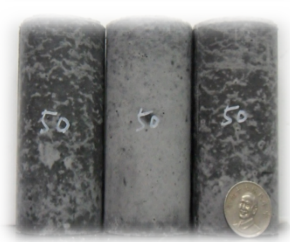
When SiO_2/Na_2O molar ratio = 1.28, the best compressive strength is 14 MPa



S/L = 0.9
(GGBS： MSWI FA =30： 70)

Experimental Procedures

(Only Alkali solution & Incinerator FA)



Water | **$NaOH_{(aq)}$** | **Na_2SiO_3**

↓

Incinerator fly ash + **Alkali solution**

L/S = 1

↓ Mixing14 mins

Pastes

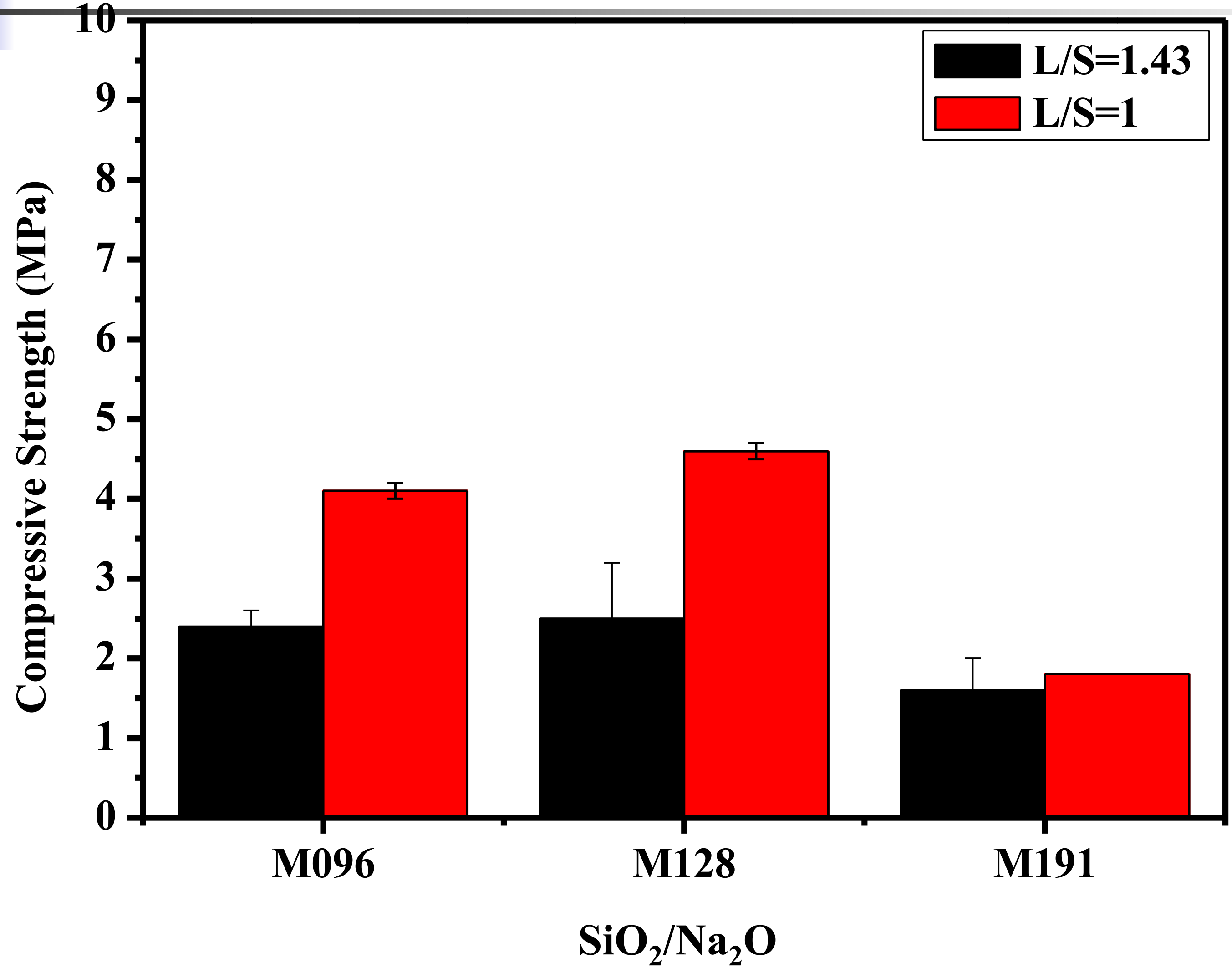
↓ Curing at room temperature for 7 days

Φ5 cm × 10 cm Cylinder Mold

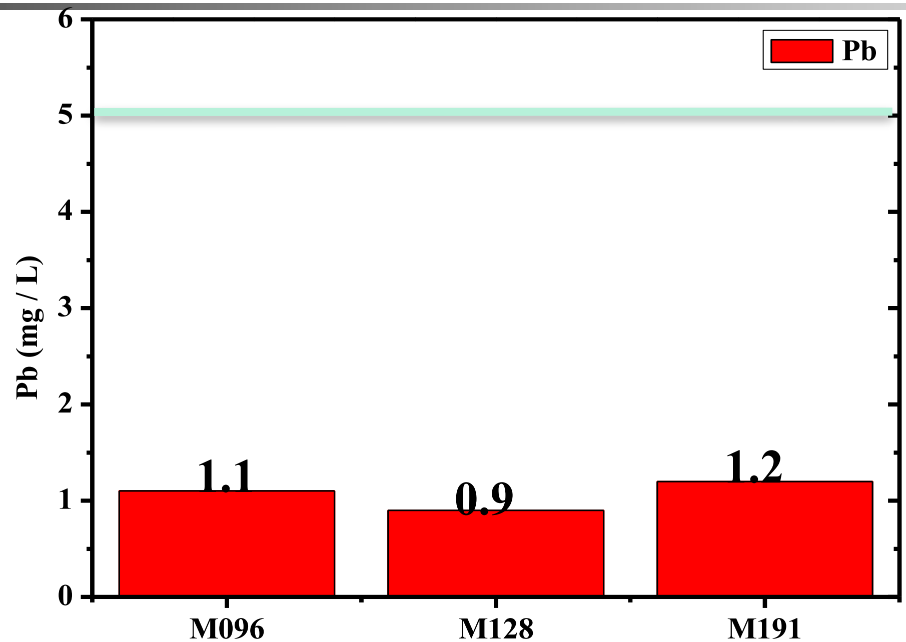
↓

- **Compressive strength**
- **Physical characterisation**
- **TCLP**
- **Specimens observation**

Effect of Compressive Strength on L/S



TCLP L/S=1.43



	Pb	Zn	Cd	Cr	Cu	Ba
Limitation	5	25	1	5	15	100
Raw Fly Ash	48.5	10.5	N.D	N.D	2.7	3.7
M096 L/S1.43 7D	1.1	N.D	N.D	N.D	N.D	0.3
M128 L/S1.43 7D	0.9	N.D	N.D	N.D	N.D	0.2
M191 L/S1.43 7D	1.2	N.D	N.D	N.D	N.D	0.8

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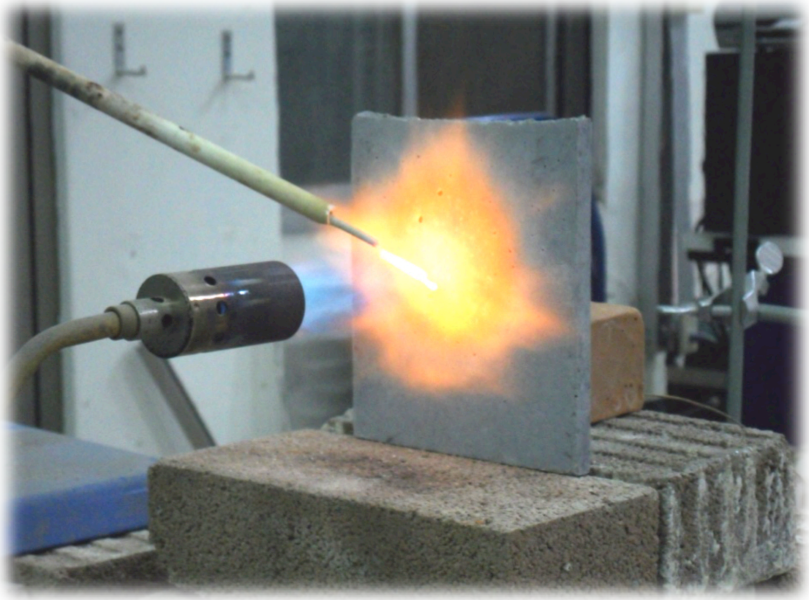
Fire Resistance & Light Weight Heat Resistance Materials

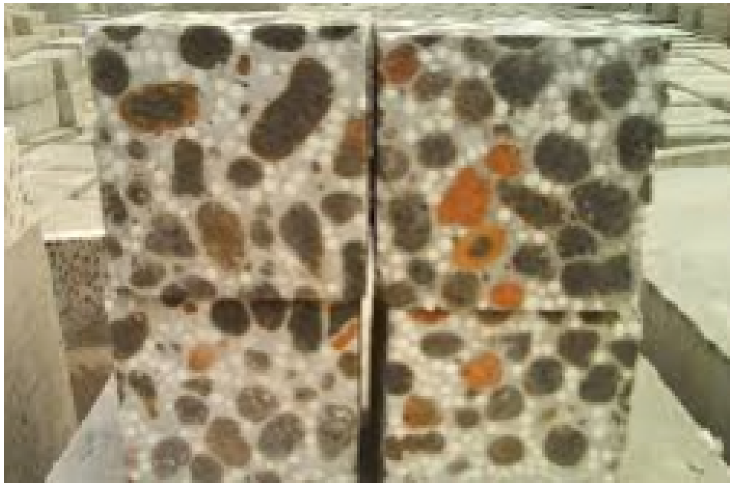


Using Perlite, Expanded Vermiculite, Foam Glass to make Light weight Fire/Heat Resistance Materials

- Fire Resistance Temperature >1100℃
- Thermal Conductivity < 0.6 W/mK 。

Cold-Bonded Light Weight Aggregate using Geopolymer Technology

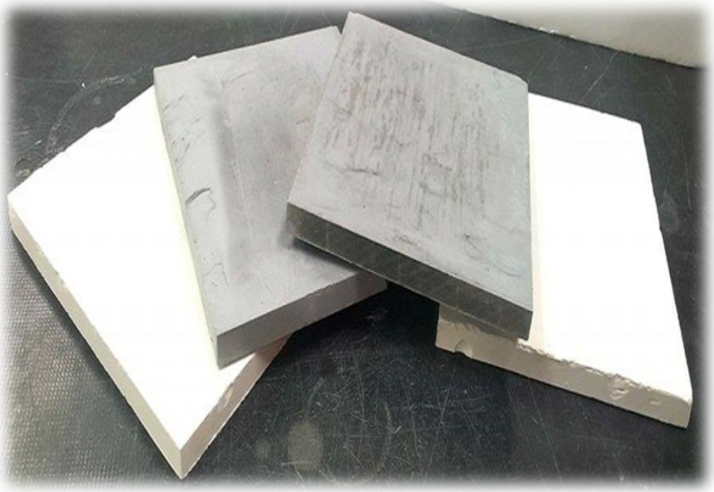
Ceramsite



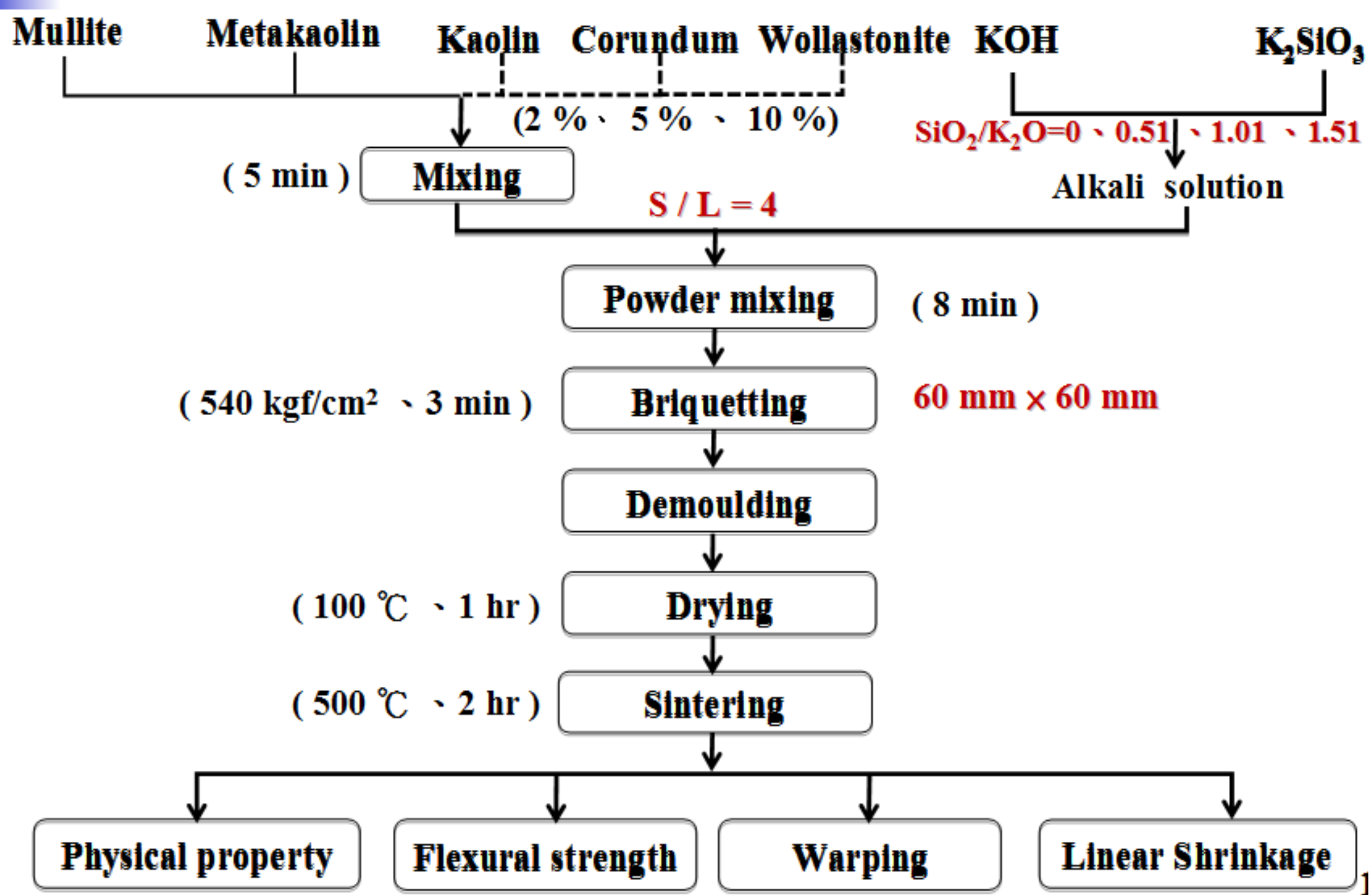
Cold-Bonded Light Weight Aggregate

- Using dimension stone cutting waste as raw material, mixed with alkali solution.
- Using granulating machine to make 6-8 mm aggregate.
- Cold-Bonded light weight aggregate can be formed after drying.
- Single particle compressive strength can be reached 4-12 MPa

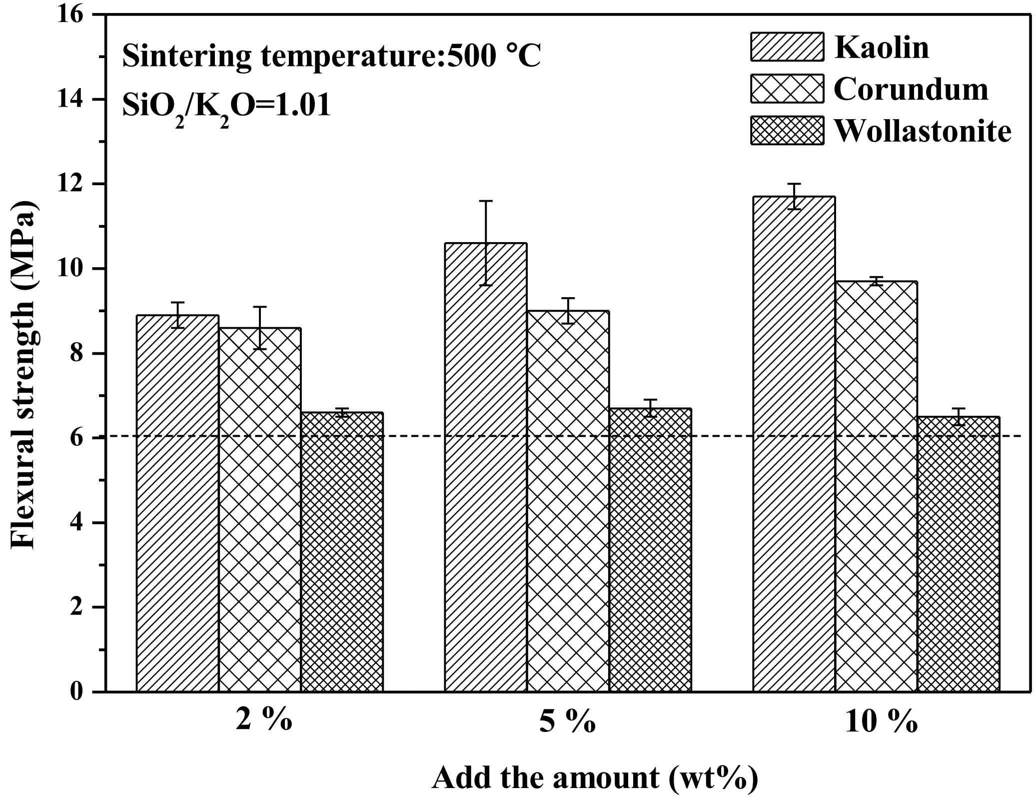
Low Temperature Sintered Tiles



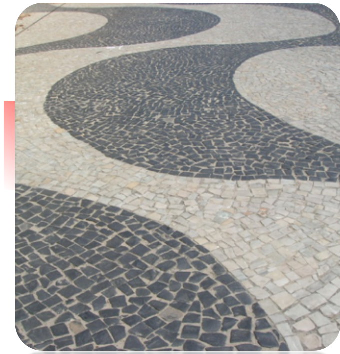
Experiment Process

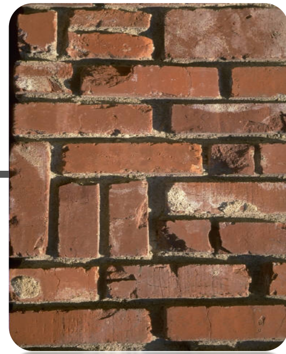


Flexural Strength



Production low temperature sintering building brick from drilling wastes using geopolymeric technology

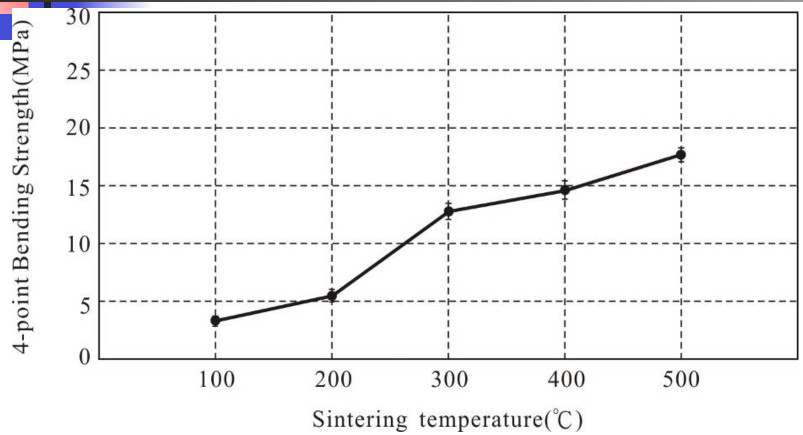




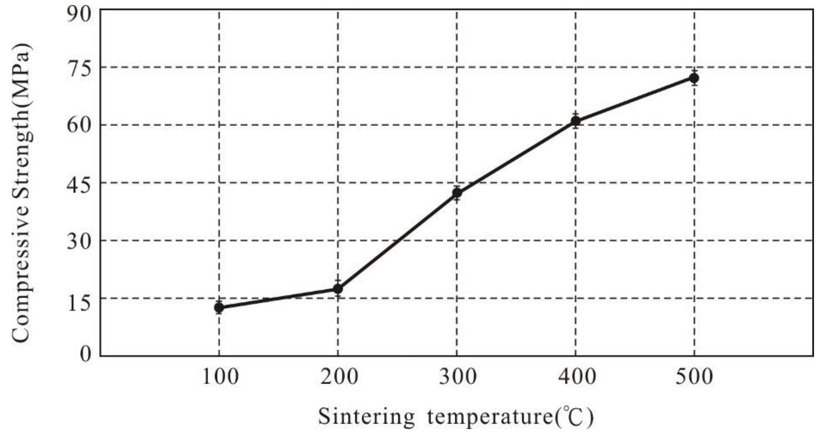

1000°C
500°C
400°C
300°C


300°C
400°C
500°C
1000°C

Physical/Mechanical Properties



Bending Strength

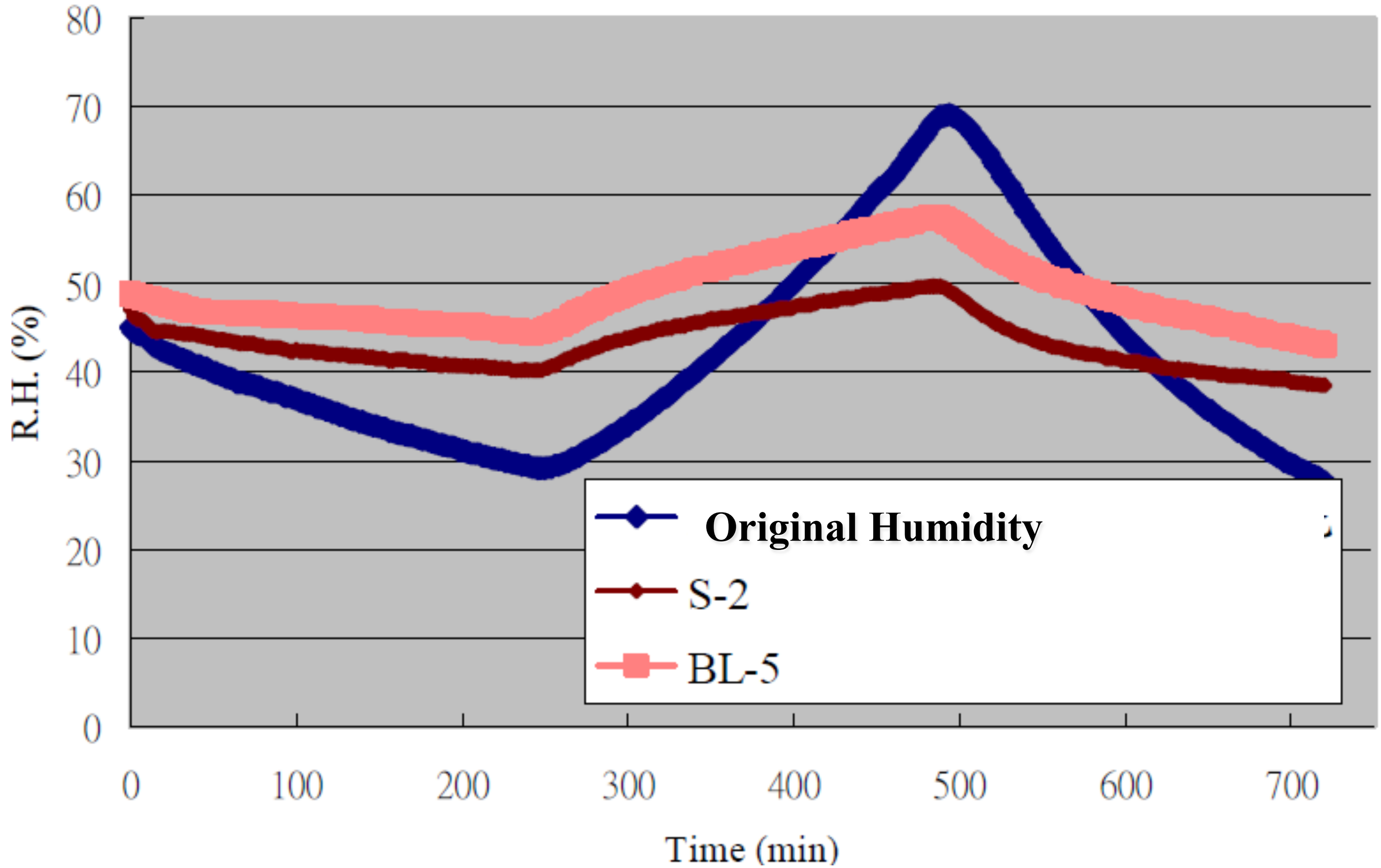


Compressive Strength

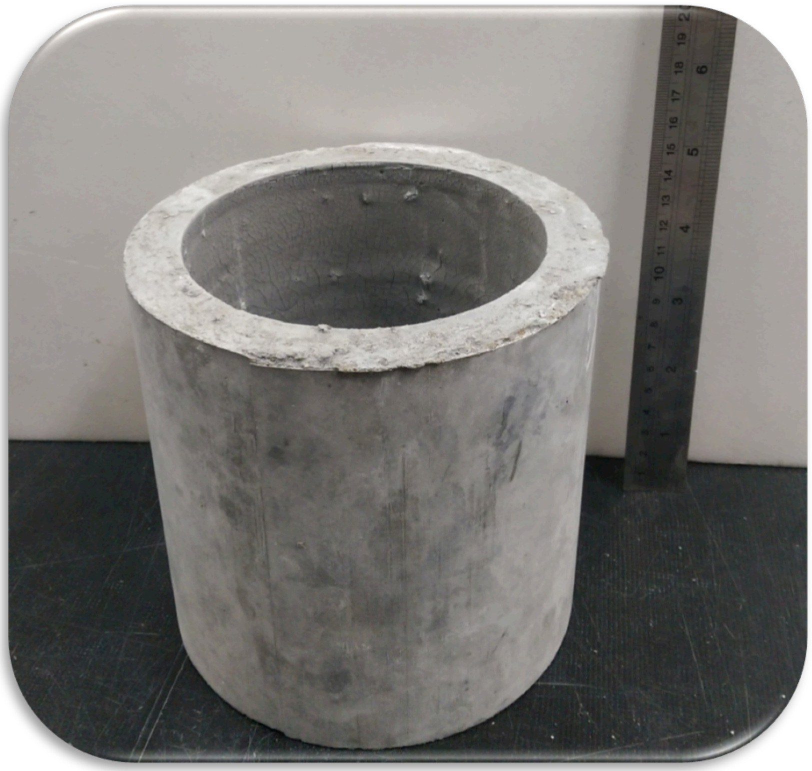
SiO_2 / Na_2O Mole ratio	Sintering Temperature °C	Density g/cm^3	Porosity %	Water Absorption rate %	shrinkage %
2	100	-	-	-	0
	200	-	-	-	0.1
	300	2.2	22.4	10.5	0.2
	400	2.3	15.0	6.6	0.3
	500	2.3	13.9	6.0	0.3

Humidity Control Painting using geopolymeric technology

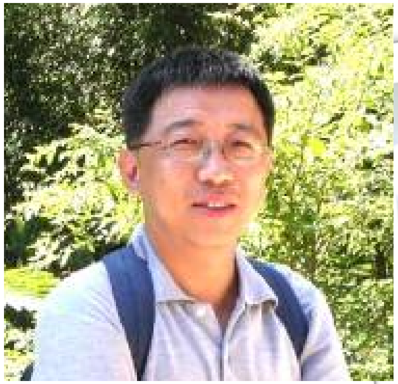
Humidity Control Properties



Pre-casting geopolymer concrete pipe



Mineral Processing Laboratroy



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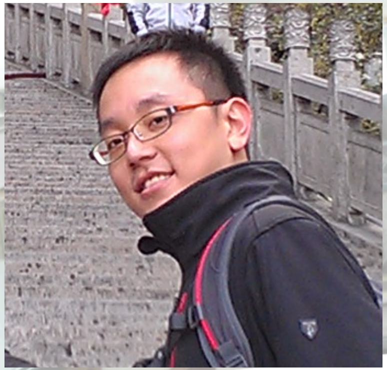

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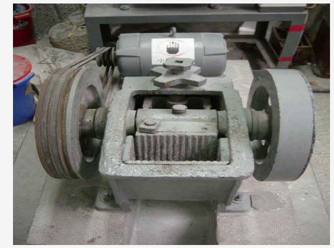
Denver flotation machine

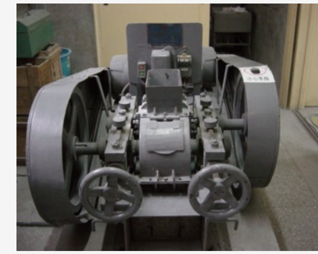
Microtrac Particle size Analyser

Cyclosizer

Jaw crusher

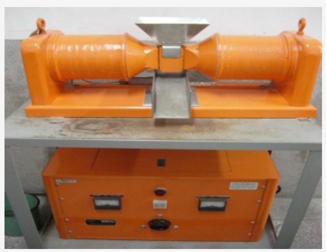


Roll crusher

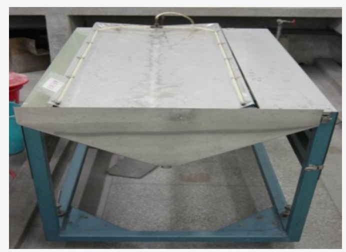


Hydrocyclone

Wet magnetic separator



Shaking table



Dry magnetic separator

Rare earth magnetic separator

DTA

BET

Furnace (1200℃)

Furnace (1550℃)

Electrostatic concentrator

Thank You for Your Attention