# Recycling and Utilization of Mine Tailings as Construction Material through Geopolymerization

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# Outline of Presentation

- Background
- Research Objectives
- Geopolymerization Technology
- Research Approach
- Preliminary Results
- Summary and Conclusions

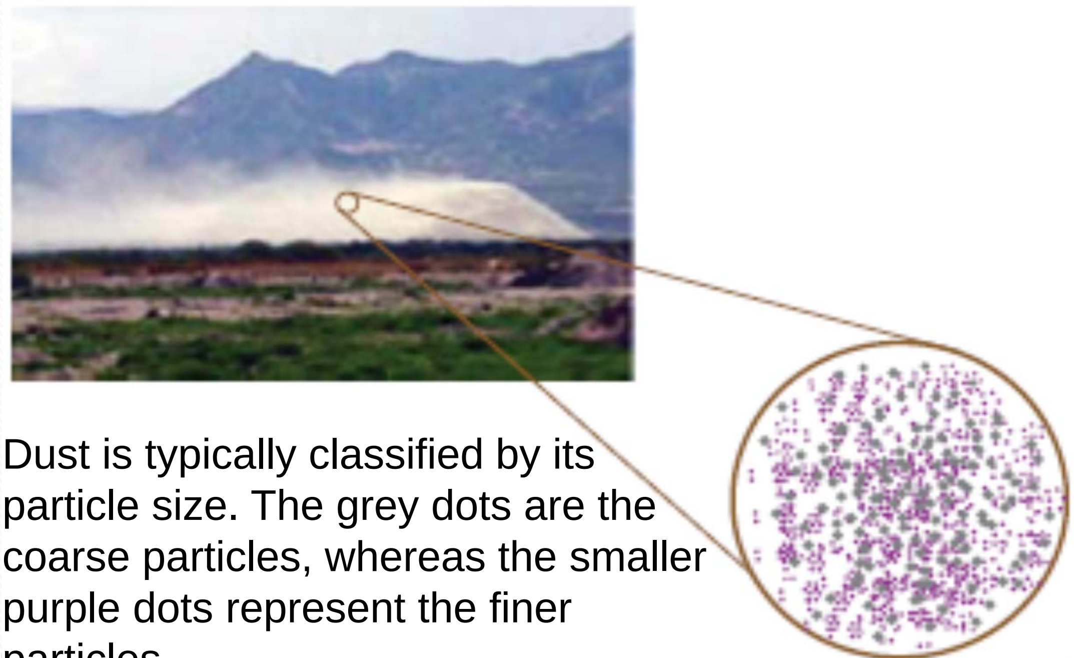
# Background

- Significant amount of mine tailings are generated each year
  - Mine tailings are transported in slurry form to large impoundments
  - Disposal of mine tailings occupies **large area of land**

# Background

- ➢ High monetary, environmental and ecological costs

Mine Tailings Dust



Dust is typically classified by its particle size. The grey dots are the coarse particles, whereas the smaller purple dots represent the finer particles.

(http://superfund.pharmacy.arizona.edu/Mine_Tailings.php)

**Adverse Impacts**

- Nuisance for nearby residents
- Reduction in traffic visibility
- Contamination of surface water, soils, groundwater, and air
- Adverse effect on human health
- Harm on animals and crops

# Background

➢ Large quantity of natural construction material is used

- Quarrying is very expensive, produces large amount of waste and damages natural landscape
- Lack of natural construction material in many areas

A stone quarry
(http://www.stonebtb.com/quarry/VI-70.shtml)

An abandoned construction aggregate quarry
(http://en.wikipedia.org/wiki/File:Stone_quarry_adelaide.JPG)

# Background

- Dilemma

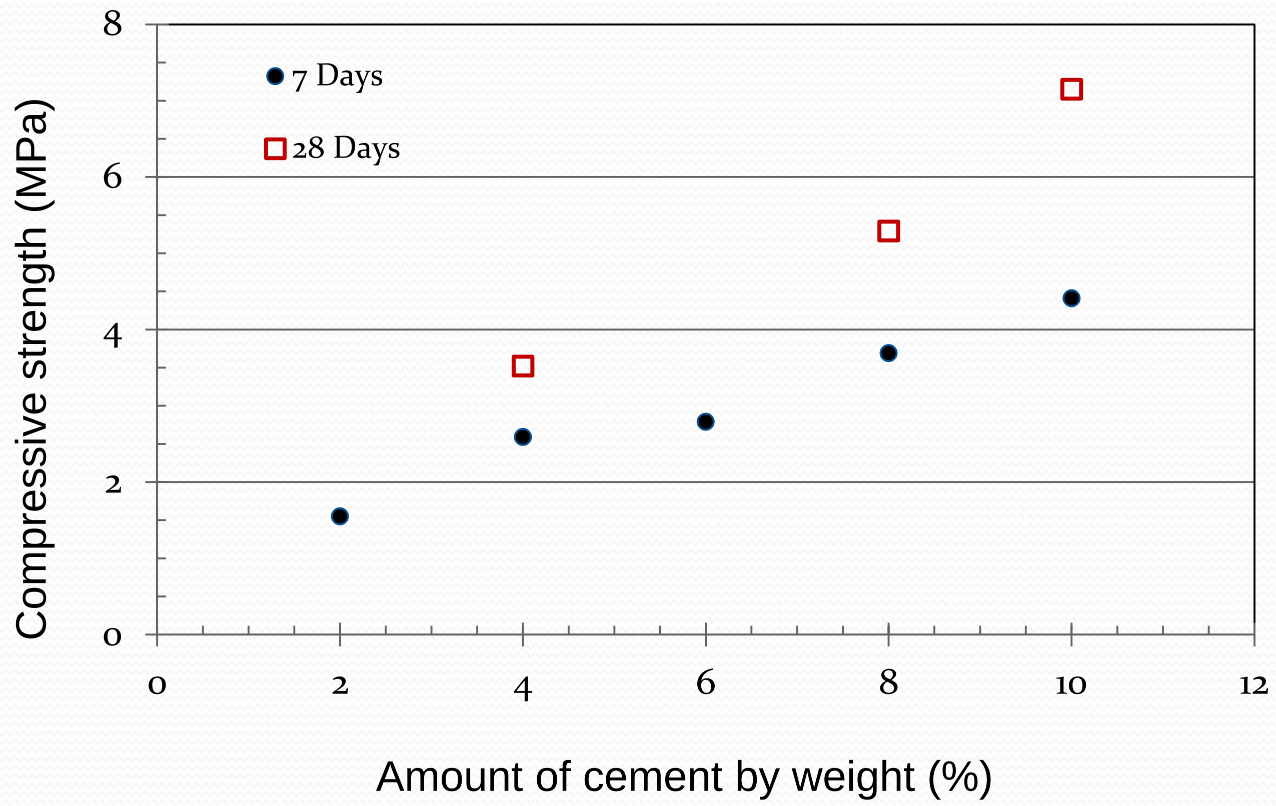
- Significant amount of mine tailings are produced and disposed of at high monetary, environmental and ecological costs

- Quarrying for natural construction material is very expensive and damages natural landscape; There is a lack of natural construction material in many areas

?

# Background

- Utilization of ordinary Portland cement (OPC) to stabilize mine tailings



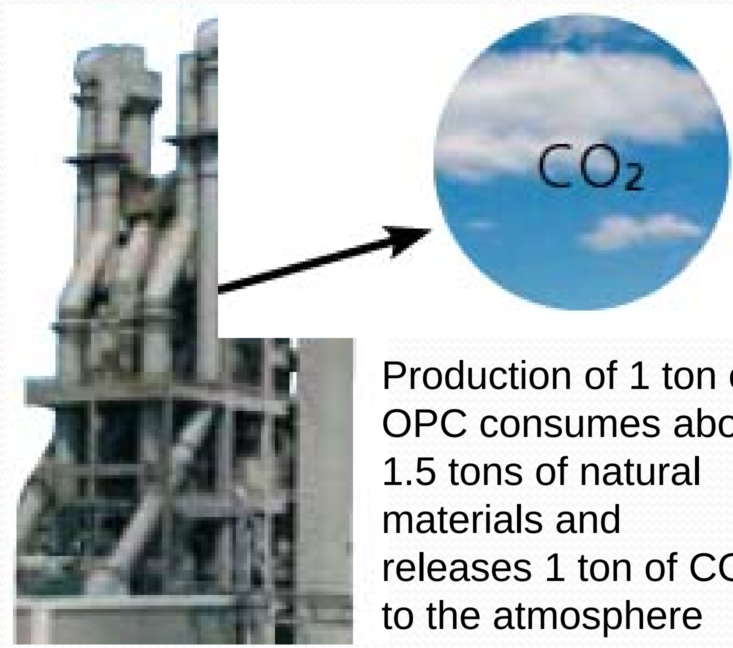

From Sultan (1979)

# Background

## ➢ Drawbacks of OPC

- Consumption of natural materials which need quarrying
- Very energy intensive
- Release of greenhouse gases
- Poor immobilization of contaminants
- Low chemical resistance

Worldwide, the cement industry alone is estimated to be responsible for about 7% of all $CO_2$ generated (Davidovits 1994; Malhotra 2000; McCaffery 2002; Arm 2003).




Production of 1 ton of OPC consumes about 1.5 tons of natural materials and releases 1 ton of $CO_2$ to the atmosphere

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# Research Objectives

The major goal is to develop an environmentally friendly and cost effective method for recycling and utilizing mine tailings as construction materials:

- Bricks
- Concrete for pavement
- Concrete for structures, e.g. bridges
- Highway base material
- Highway embankment material

**No OPC is used !**

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# Geopolymerization Technology

- Geopolymerization is a relatively new technology that transforms aluminosilicate materials into useful products called geopolymers

**Mine Tailings**

\+

**Alkali (NaOH)**

\+

**Water**


=

**Geopolymer paste**

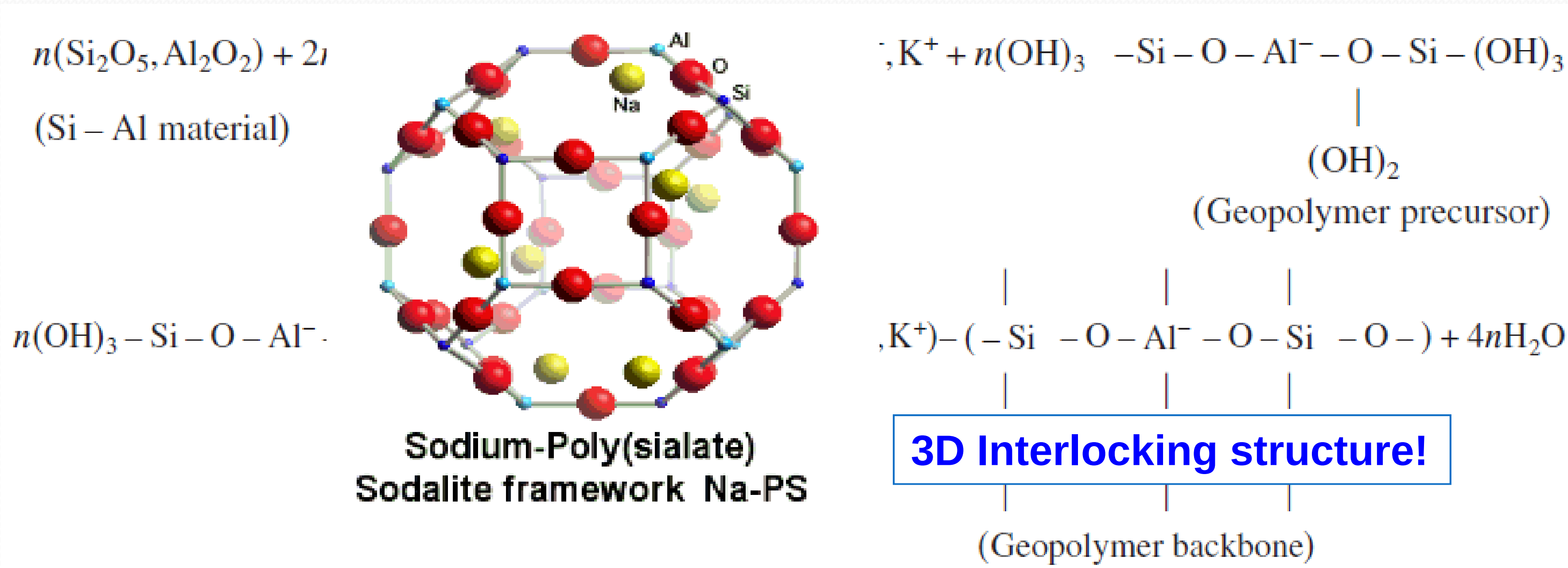
Reaction proceeds at room or slightly elevated temperature

# Geopolymerization Technology

- Geopolymerization consists of 2 basic steps:

(1) Dissolution of solid aluminosilicate oxides by alkali to produce small reactive silica and alumina

(2) Polycondensation process leading to formation of amorphous to semicrystalline polymers



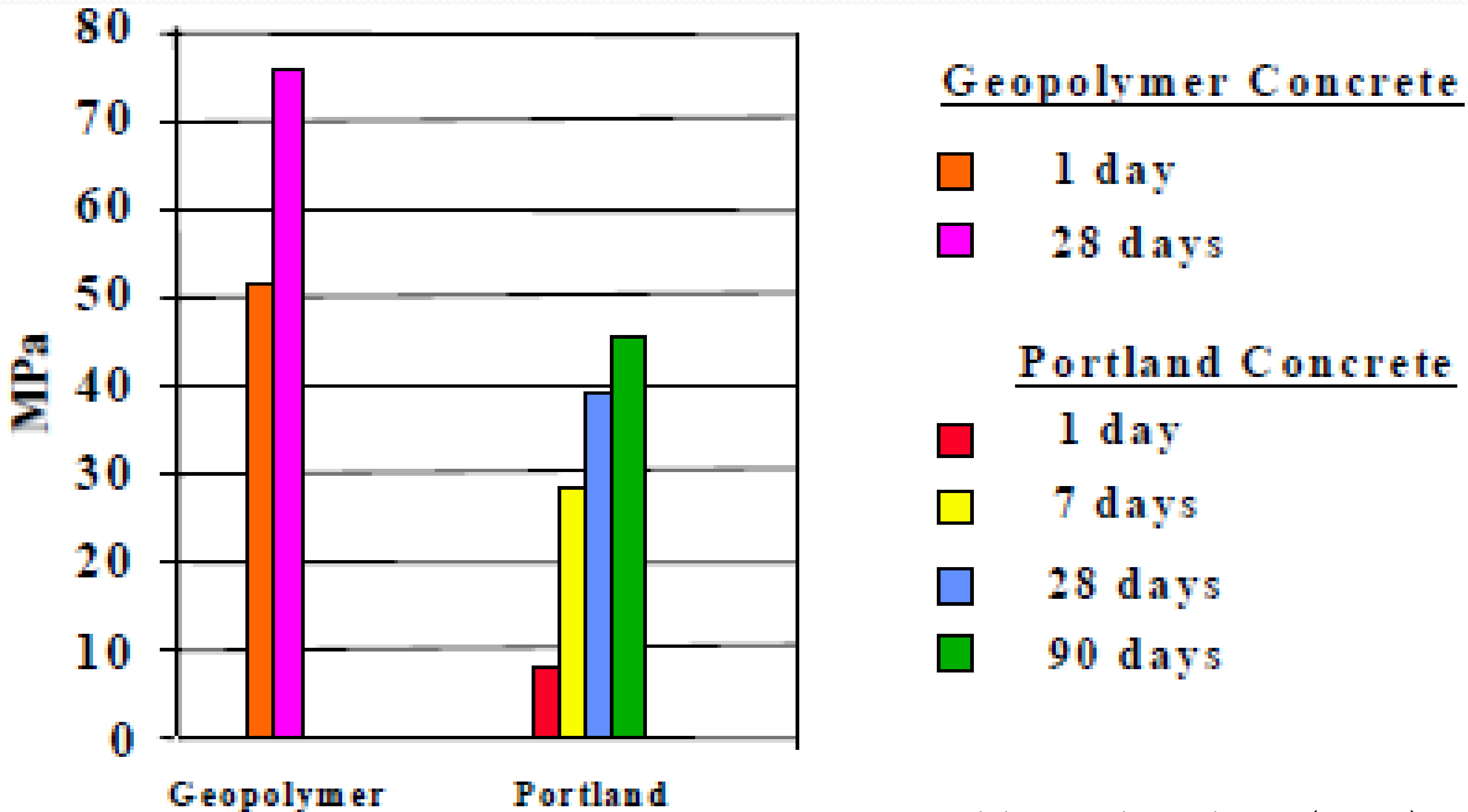

Sodium-Poly(sialate)
Sodalite framework Na-PS

# Geopolymerization Technology

## Advantages of geopolymer over OPC

- Abundant raw materials resources
- Energy saving and environment protection
- Good volume stability
- Reasonable strength gain in short time
- Ultra-excellent durability
- High fire resistance and low thermal conductivity
- Ability to immobilize toxic and hazardous wastes
- Superior resistance to chemical attack

# Geopolymerization Technology




Dreschler and Graham (2005)

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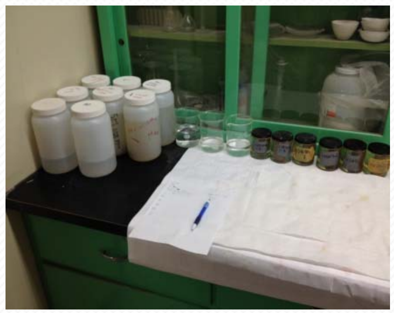
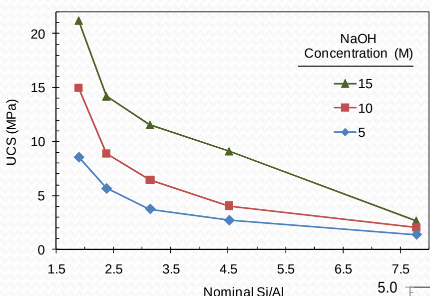
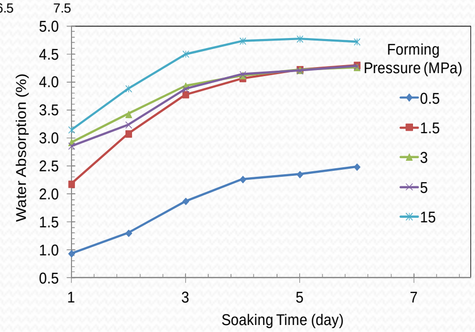
# Multi-scale and Multi-disciplinary Research Approach

## Macro-scale Study

- Uniaxial compression tests
- Split tensile tests
- Water absorption tests
- Leaching/durability tests

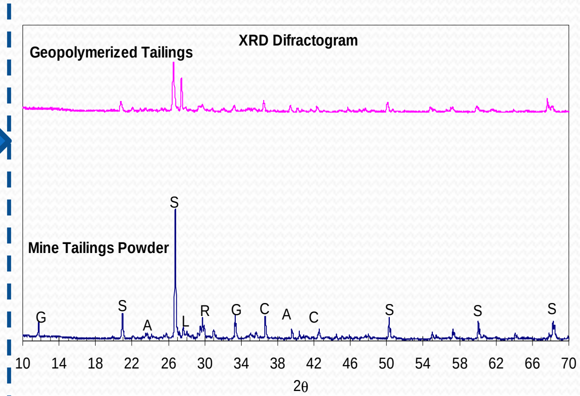


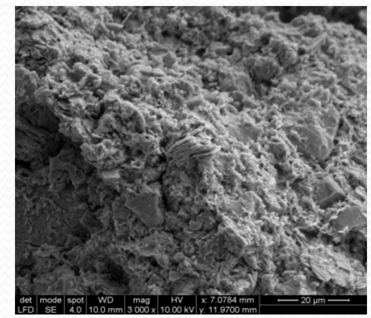






## Micro/nano-scale Investigation

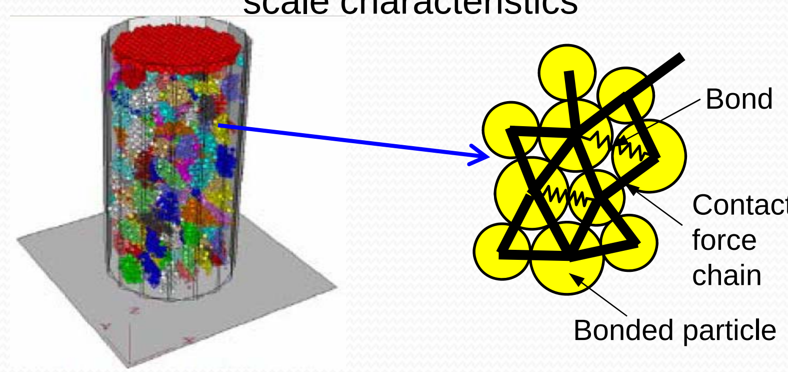
- X-ray diffraction (XRD) characterization
- Scanning electron microscopy (SEM) imaging
- Atomic force microscopy (AFM) nanoindentation





## DEM Simulations

- Link macro-scale behavior and micro/nano-scale characteristics



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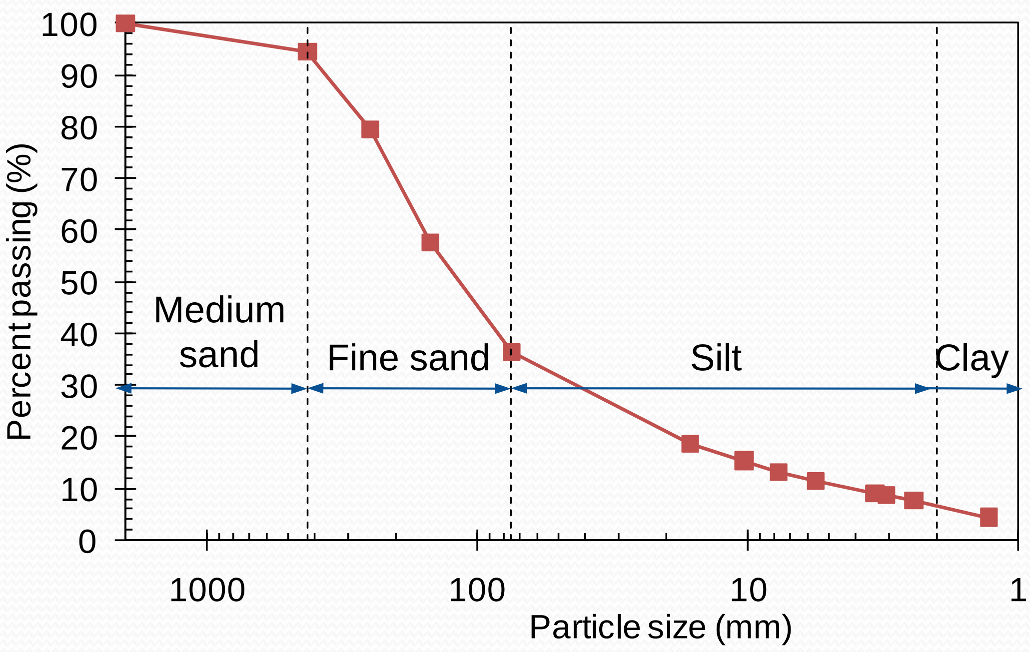
# Mine Tailings-Based Geopolymer Bricks

## ➢ Materials Used

- Mine tailings provided by a local mining company
- Sodium hydroxide
- Deionized water



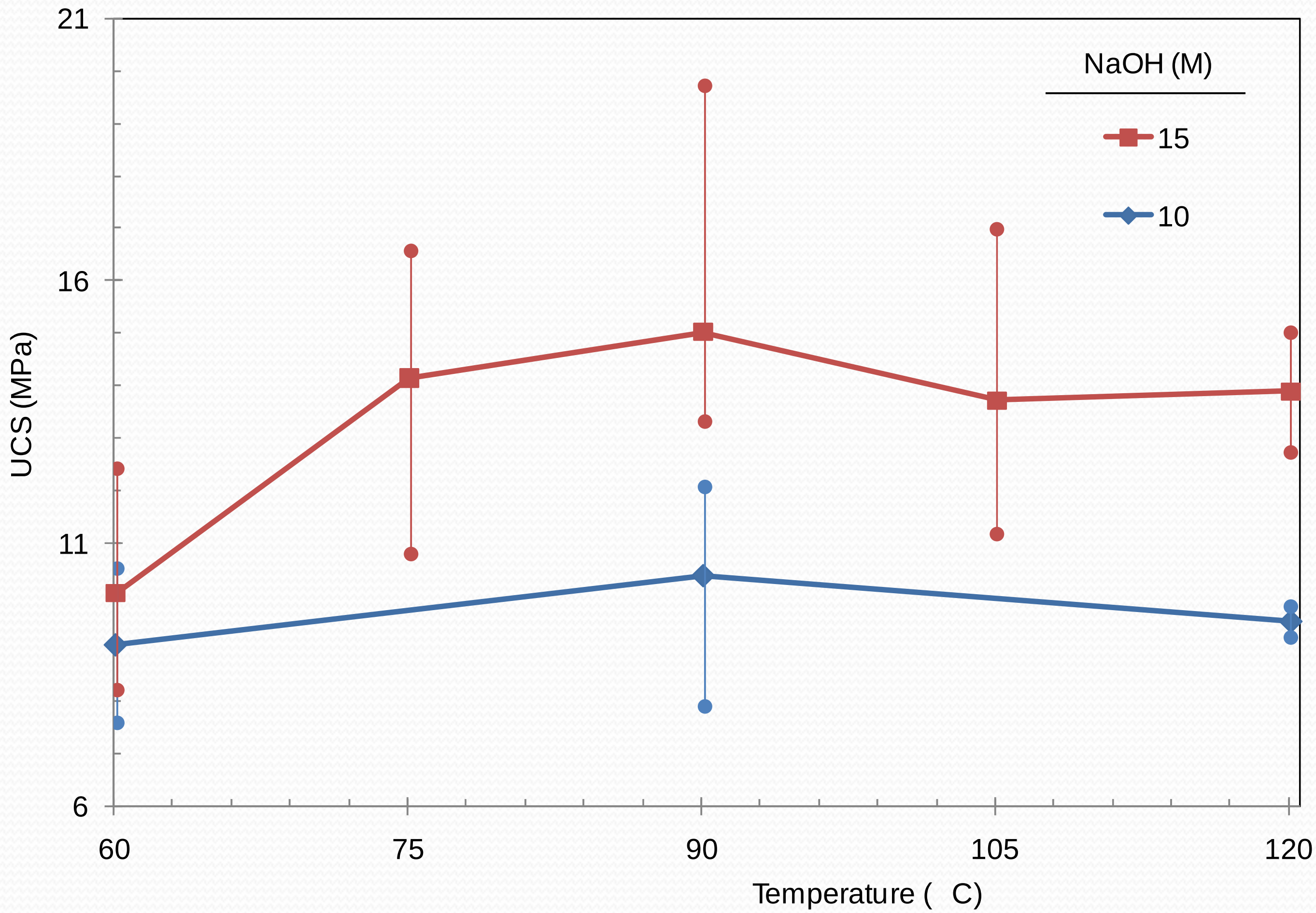

| Chemical Compound | (%) |
|---|---|
| $SiO_2$ | 64.8 |
| $Al_2O_3$ | 7.08 |
| $Fe_2O_3$ | 4.33 |
| CaO | 7.52 |
| MgO | 4.06 |
| $SO_3$ | 1.66 |
| $Na_2O$ | 0.90 |
| $K_2O$ | 3.26 |

# Mine Tailings-Based Geopolymer Bricks

- Small MT geopolymer samples
  - 34.5 mm diameter and 69.0 mm length
- Four major factors investigated:
  - Sodium hydroxide solution concentration (10 and 15 M)
  - Initial water content (8 to 18%)
  - Forming pressure (0 to 35 MPa)
  - Curing temperature (60 to 120 °C)
- Tests performed:
  - Unconfined compression tests
  - Water absorption tests
  - SEM imaging/XRD analysis
  - Leaching tests

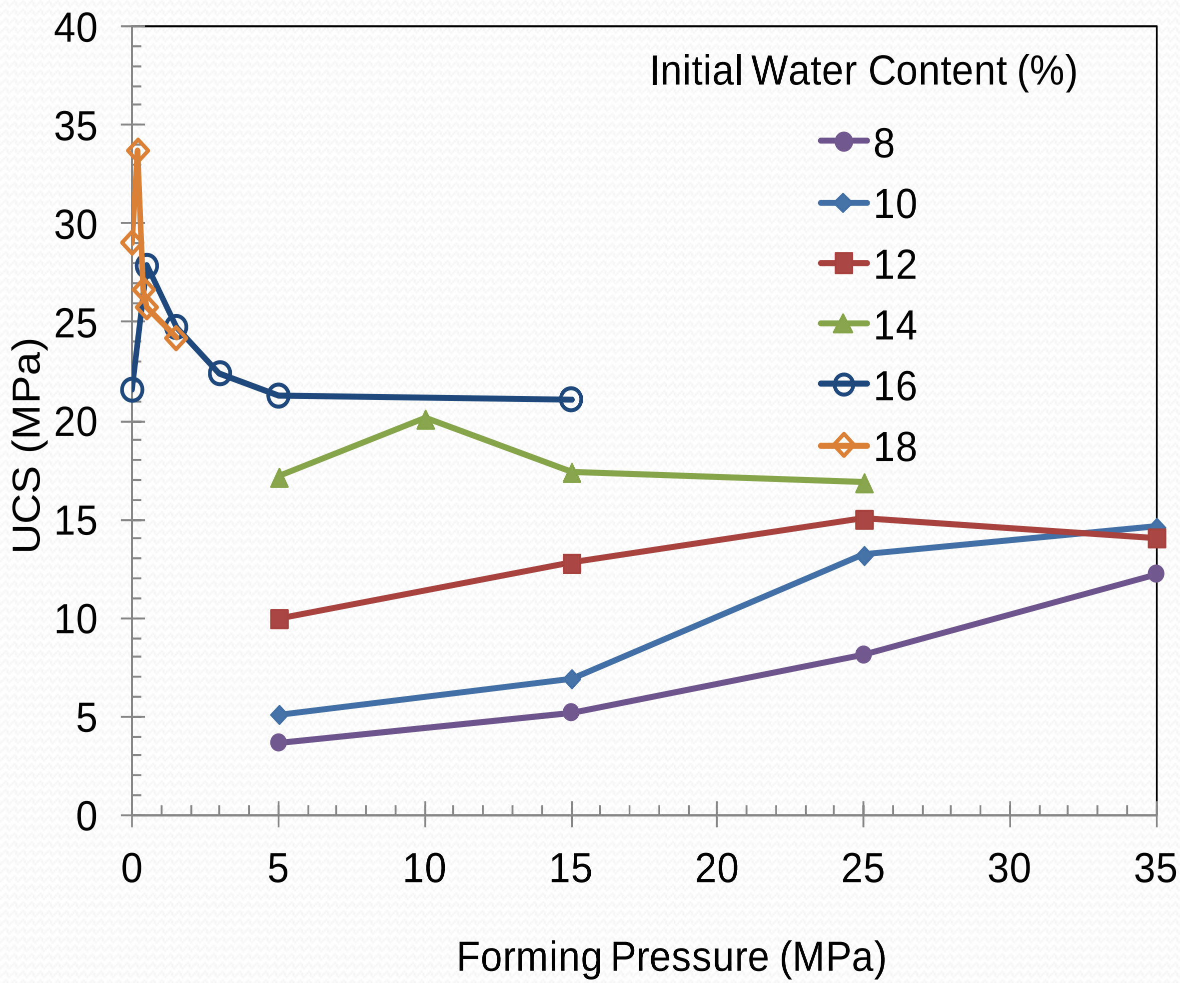
Precompression

# Unconfined Compressive Strength



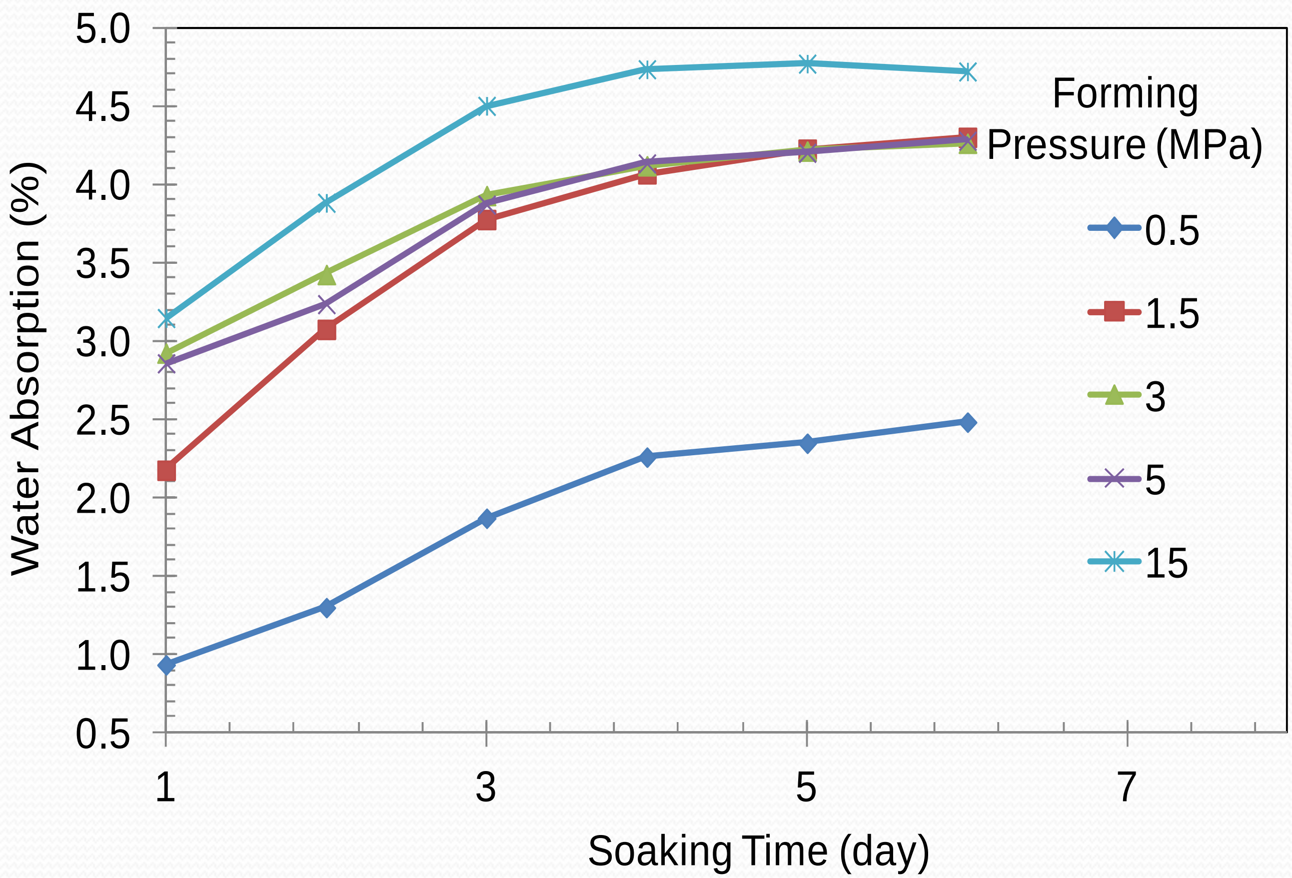

UCS versus curing temperature for specimens prepared at 12% initial water content, 25 MPa forming pressure, and respectively 10 and 15 M NaOH concentrations and cured for 7 days

# Unconfined Compressive Strength



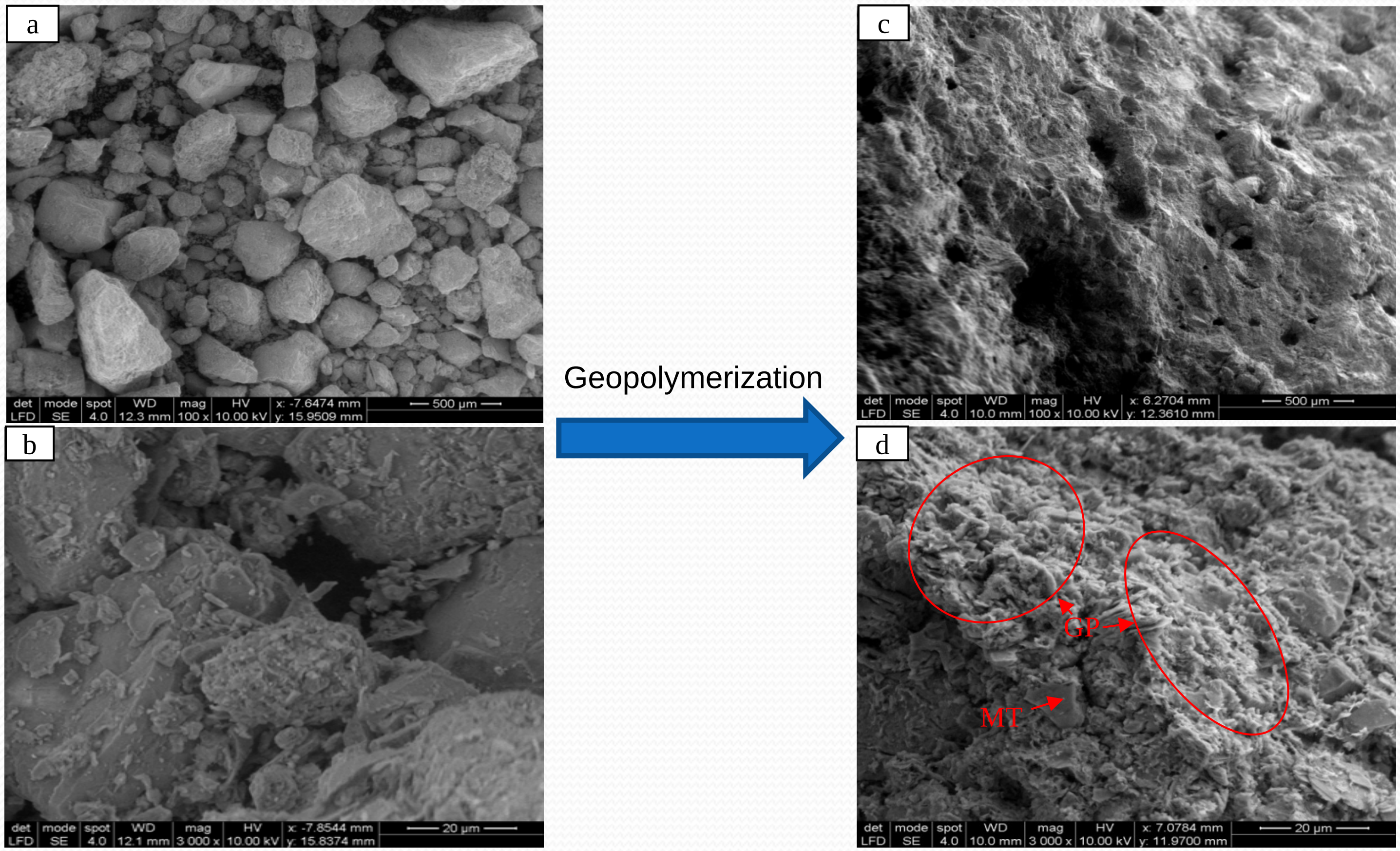

UCS versus forming pressure for specimens prepared at different initial water contents and 15 M NaOH concentration and cured for 7 days at 90 °C

# Water Absorption




Water absorption versus forming pressure with different soaking times for specimens prepared at 16% initial content, 15 M NaOH concentration and different forming pressures and cured at 90 °C for 7 days

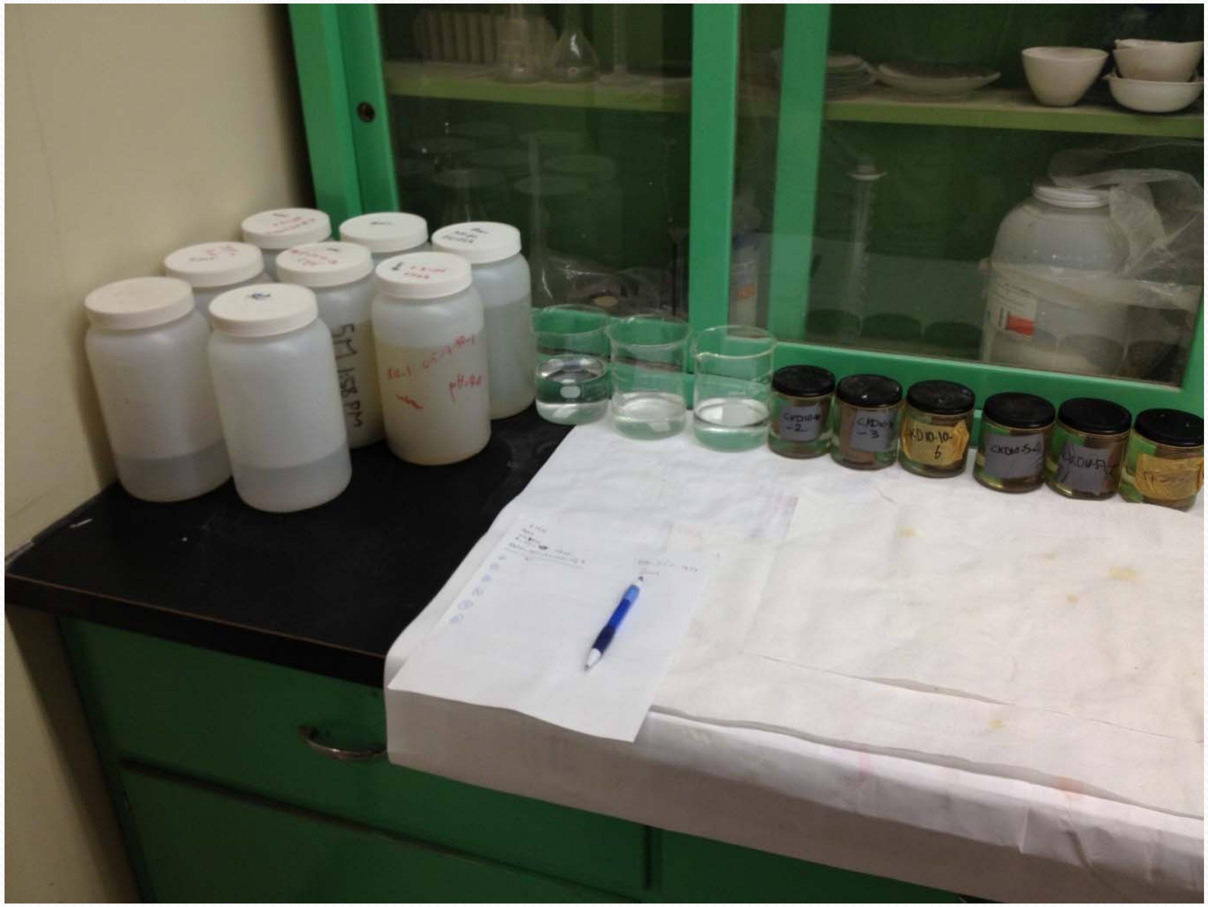
# SEM Micrographs




MT

Geopolymerized MT at 16% initial content, 15 M NaOH concentration and 0.5 MPa forming pressure and cured at 90 °C for 7 days

# Leaching Tests



Geopolymer samples immersed in solution with pH = 4.0 and 7.0

# Leaching Test Results

➢ **Elemental concentrations after leaching for 90 days (pH = 4.0)**

| | | Mg | Al | Cr | Mn | Ni | Co | Cu | Zn | As | Se | Cd | Ba | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mine tailings | | 497.2 | 1.24 | 0.0 | 8.8 | 0.02 | 0.03 | 4.0 | 1.9? | 0.0 | 0.19 | 0.0 | 0.08 | 0.0 |
| Brick | | 0.59 | 0.61 | 0.0 | 0.08 | 0.0 | 0.0 | 0.14 | 0.06 | 0.0 | 0.04 | 0.0 | 0.05 | 0.0 |
| Standard Limits | EPA | NA | NA | 5.0 | NA | 5.0 | NA | NA | NA | 5.0 | 1.0 | 1.0 | 100 | 5.0 |
| | DIN | NA | NA | NA | NA | NA | NA | 2.0 to 5.0 | 2.0 to 5.0 | 0.1 to 0.5 | NA | NA | NA | 0.5 to 1.0 |
| | Greek | NA | 2.5 to 10.0 | NA | 1.0 to 2.0 | 0.2 to 0.5 | NA | 0.25 to 0.5 | 2.5 to 5.0 | NA | NA | NA | NA | 0.1 to 0.2 |

# Production and Testing of Real Size Bricks

# Mechanical Tests Results

➢ **Meet ASTM requirements for different applications**

| Title of specification | ASTM Designation | Type/Grade | Minimum UCS (MPa) | Maximum water absorption (%) |
|---|---|---|---|---|
| Structural clay load bearing wall tile | C34-03 | LBX | 9.6 * | 16 |
| | | LBX | 4.8 ** | 16 |
| | | LB | 6.8 * | 25 |
| | | LB | 4.8 ** | 25 |
| Building brick | C62-10 | SW | 20.7 | 17 |
| | | MW | 17.2 | 22 |
| | | NW | 10.3 | No limit |
| Solid masonry unit | C126-99 | Vertical coring | 20.7 | NA |
| | | Horizontal coring | 13.8 | NA |
| Facing brick | C216-07a | SW | 20.7 | 17 |
| | | MW | 17.2 | 22 |
| Pedestrian and light traffic paving brick | C902-07 | SW | 55.2 | 8 |
| | | MW | 20.7 | 14 |
| | | NW | 20.7 | No limit |

Notes: LBX = load bearing exposed; LB = load bearing non-exposed; *end construction use; **side construction use; SW = severe weathering; MW = moderate weathering; NW = negligible weathering.

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# Summary and Conclusions

- **The following conclusions can be drawn from the preliminary work on MT-based geopolymer bricks:**
  - ❖ NaOH concentration, initial water content, forming pressure, and curing temperature are four major factors affecting the physical and mechanical properties of MT-based geopolymer bricks.
  - ❖ By selecting appropriate preparation conditions, geopolymer bricks can be produced from MT to meet the ASTM requirements.
  - ❖ The leaching tests show that the MT-based geopolymer bricks are environmentally safe.
- **Further work is being conducted on using geopolymerized MT as other types of construction materials.**

# Acknowledgement


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  Saeed Ahmari, Rui Chen, Xiaobin Ding, Xin Ren (Graduate students)
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**Thank You!**