Complete Recycling and Utilization of Waste Concrete through Geopolymerization

Lianyang Zhang, PhD, PE

Department of Civil Engineering and Engineering Mechanics
University of Arizona

November 19, 2014

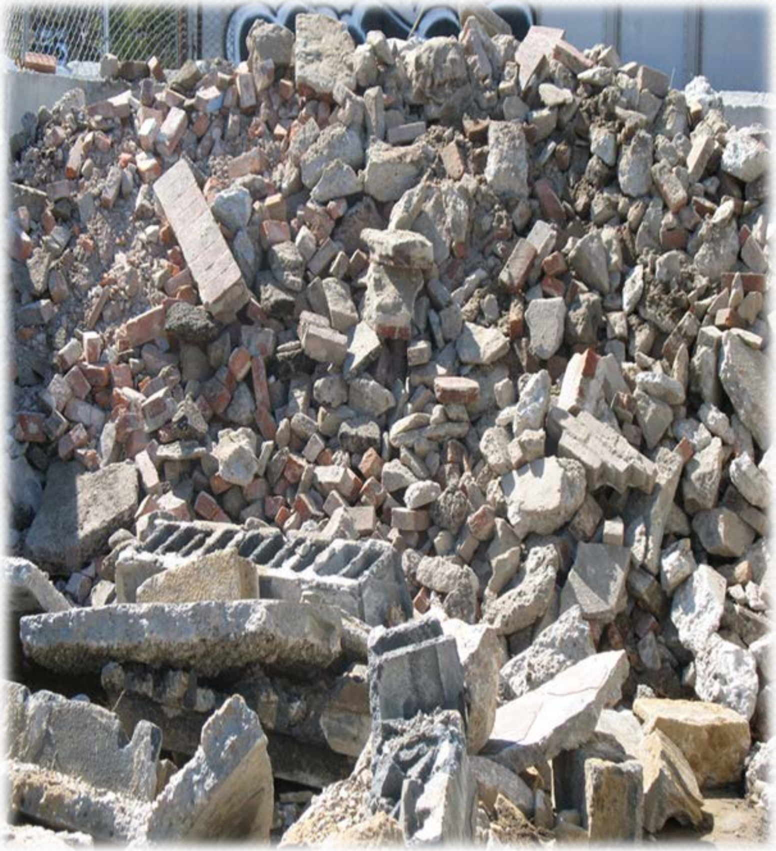
Outline of Presentation

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

Background

- The U.S. infrastructure receives an overall grade of D^+ and is in urgent need to be repaired and upgraded
- Repairing and upgrading existing infrastructure generates significant amount of concrete waste
- Addressing the significant amount of concrete waste is a great challenge

- How to address the significant amount of waste concrete in a sustainable way?



❑ Crushing of waste concrete for recycling

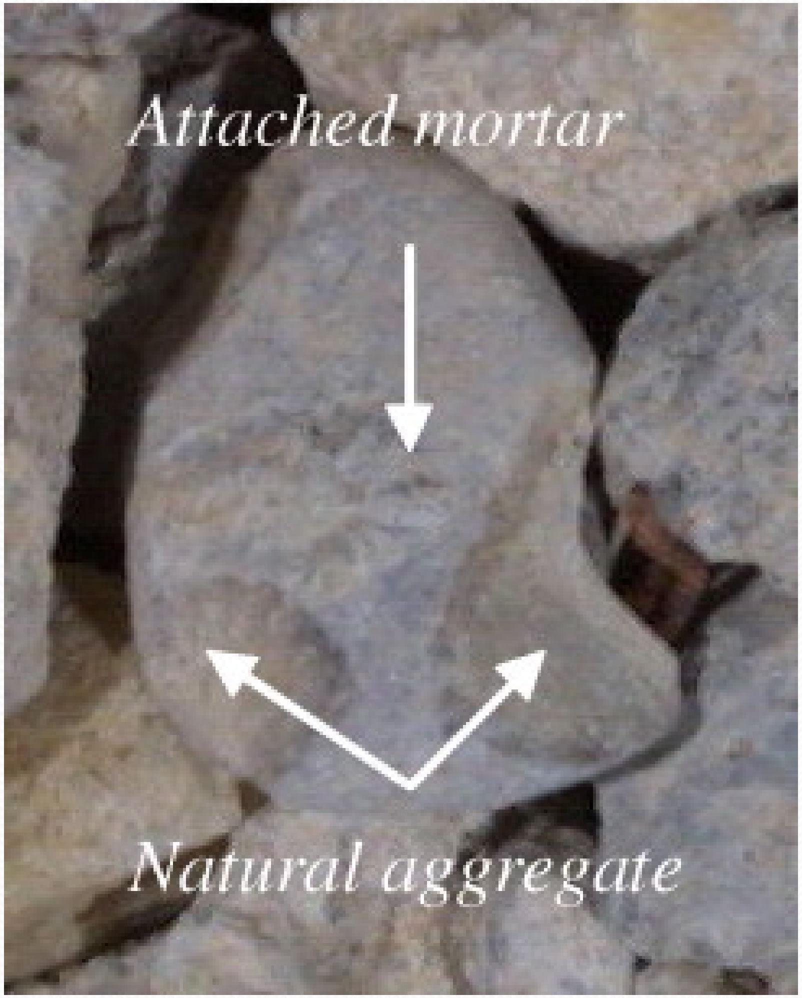
❑ Utilization of crushed waste concrete without processing

- Mainly for low-specification applications
  - Road base
  - Embankment fill
  - …

Crushed-concrete base

❑ Utilization of crushed waste concrete for structural concrete

❑ Low quality of RCA



Compared to natural aggregate (NA), RCA has

- larger water absorption,
- lower bulk density,
- higher porosity, and
- higher increased crushability.

➡

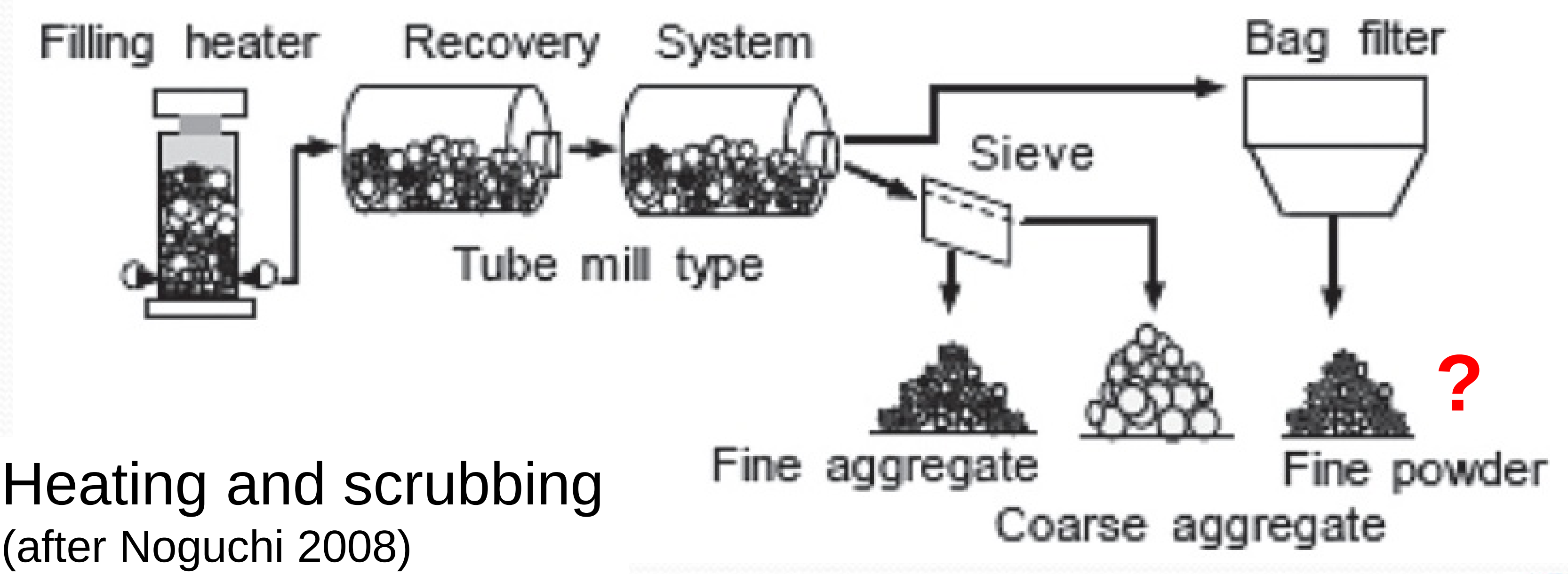
Limited utilization of RCA in structural concrete

$\leq 30\%$

❑ Refining of RCA

- Mechanical grinding
- Heating and scrubbing
- Chemical processing
- …

Energy consumption **?**



Heating and scrubbing
(after Noguchi 2008)

❑Limitations of current WC recycling methods

❖Recycling of both RCA and fines

- Low specification applications

❖Recycling of RCA

- Only partially replace natural aggregate $\leq$ 30%
- Reprocessing of RCA → Energy consumption
- Fines?

Outline of Presentation

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

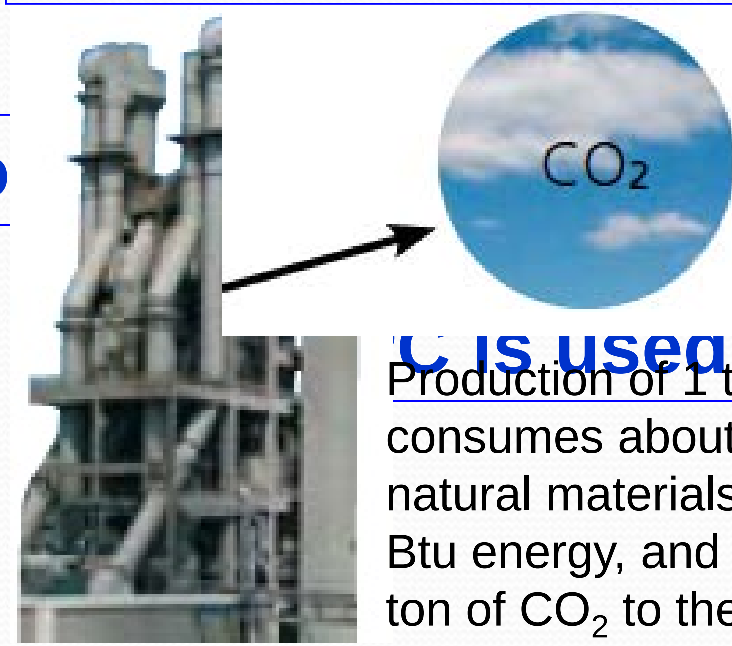
Research Objectives

The major goal is to develop an environmentally friendly and cost effective method for complete recycling and utilization of waste concrete (both RCA and fines) in concrete production

Address drawbacks of OPC

Geo … nology

C is used !



Production of 1 ton of OPC consumes about 1.5 tons of natural materials & 4.8 million Btu energy, and releases 1 ton of CO_2 to the atmosphere

Outline of Presentation

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

Geopolymerization Technology

- Geopolymerization is a relatively new technology that transforms aluminosilicate materials through chemical reaction with an alkaline solution into a useful product called geopolymer

Aluminosilicate

+

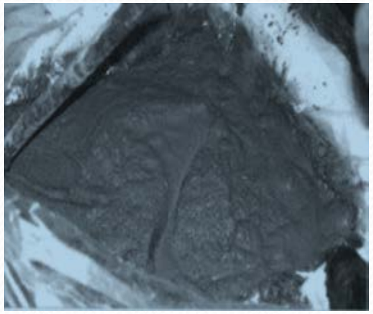
Alkali (NaOH)

+

Water

=

Geopolymer paste

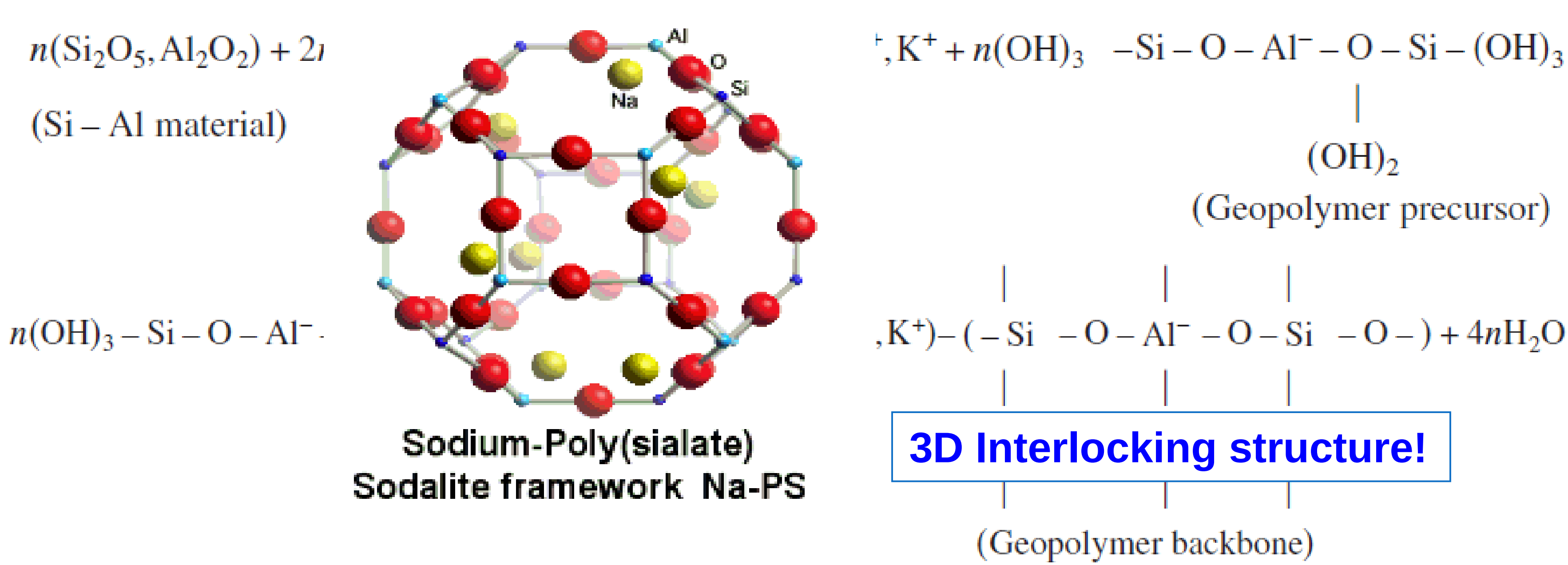


Reaction proceeds at room or slightly elevated temperature

❑ 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



❑ Advantages of geopolymer over OPC

- Energy saving and environment protection
- Wastes (fly ash, mine tailings, …) as source material
- Good volume stability
- Reasonable strength gain in short time
- Excellent durability
- High fire resistance and low thermal conductivity
- Ability to immobilize toxic and hazardous wastes
- Superior resistance to chemical attack
- …

Outline of Presentation

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

Research Approach

❑Hypotheses

- The fines of crushed waste concrete (WCF) can be used together with fly ash to produce geopolymer paste/mortar with desired properties

WCF

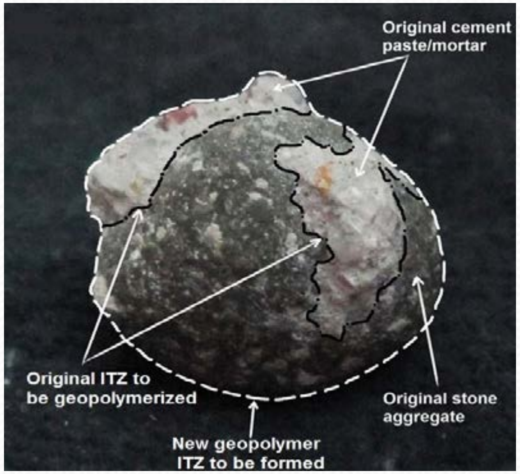
+

Fly ash

+

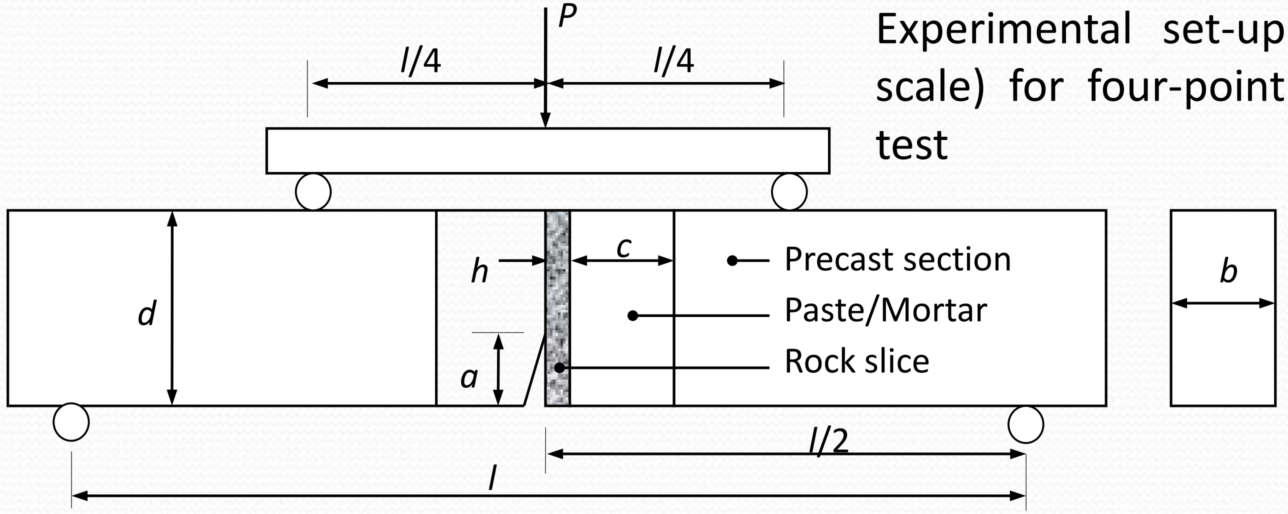
=

- The RCA with original "porous" cement paste/mortar adhering to them can be (partially) geopolymerized to generate a good bond between the aggregate and the geopolymer paste/mortar



❑Research Tasks

- Study the mechanical behavior of geopolymer paste/mortar produced from WCF and fly ash at different conditions
- Study the bonding between RCA and geopolymer paste/mortar
- Study the mechanical behavior of geopolymer concrete produced from WCF/fly ash and RCA at different conditions



Experimental set-up (not to scale) for four-point bending test

Outline of Presentation

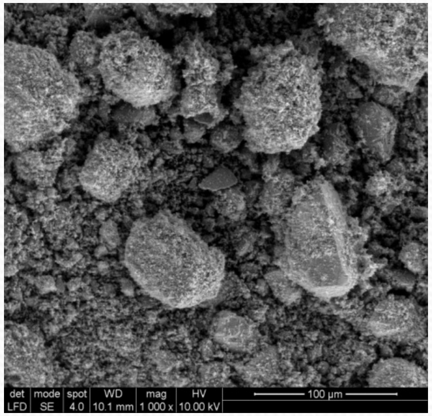
- Background
- Research Objectives
- Geopolymerization Technology
- Research Approach
- **Results**
- Summary and Conclusions

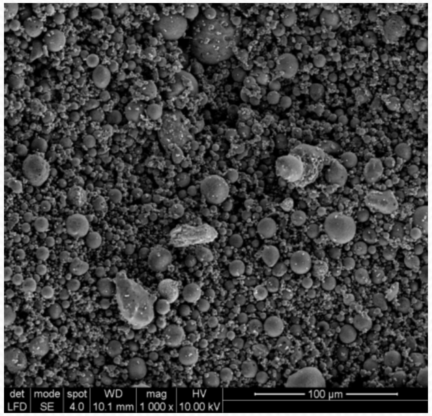
Results

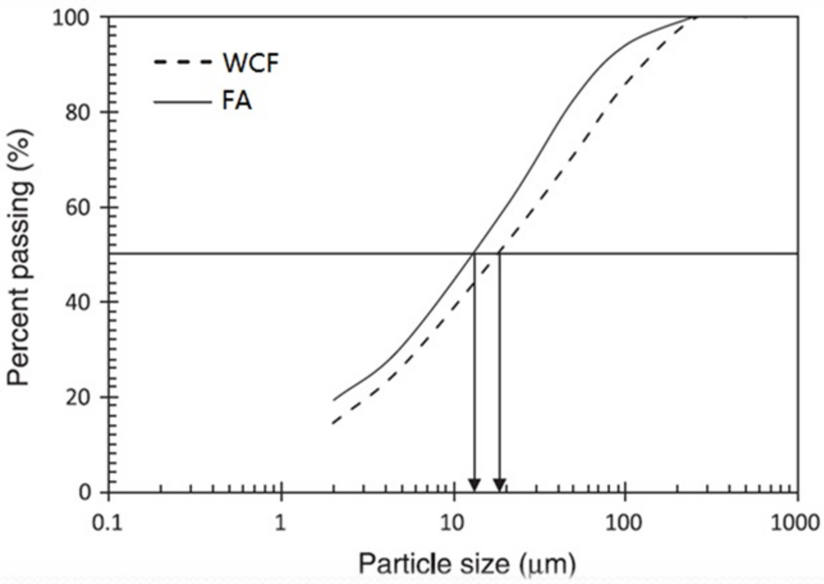
❑ Waste concrete fines (WCF) and fly ash (FA) used

Chemical Compound	WCF (%)	FA (%)
SiO_2	40.1	57.5
CaO	20.6	6.0
Al_2O_3	9.6	29.3
Fe_2O_3	3.5	2.95
K_2O	2.3	NA
H_2O	2.2	NA
MgO	2.1	1.36
Na_2O	1.7	2.6

(Waste concrete is the tested concrete specimens in the structural lab at UA)







Experiments on WCF/FA-based geopolymer paste

WCF

FA

NaOH

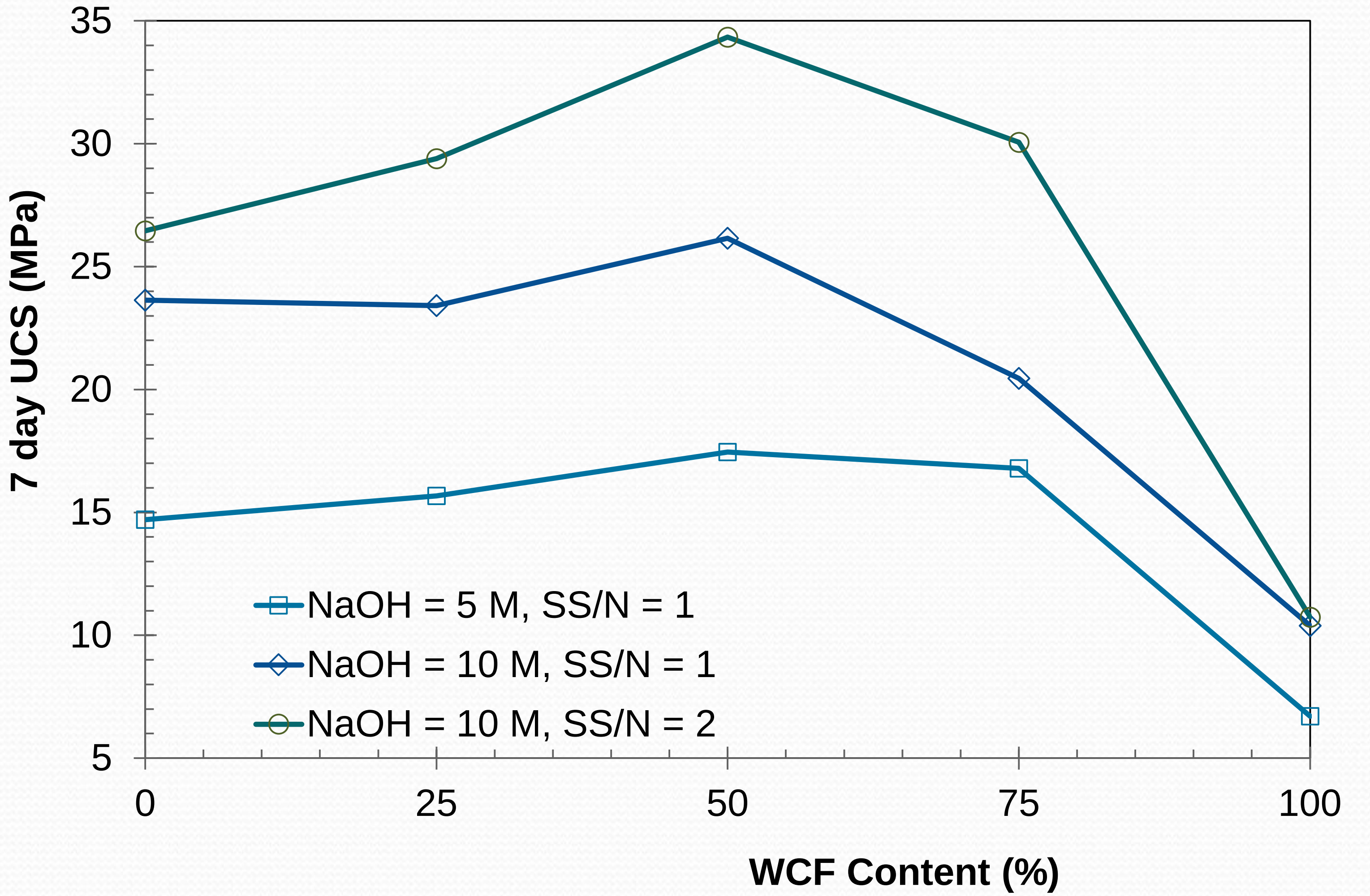
DI-H_2O

NaOH Solution

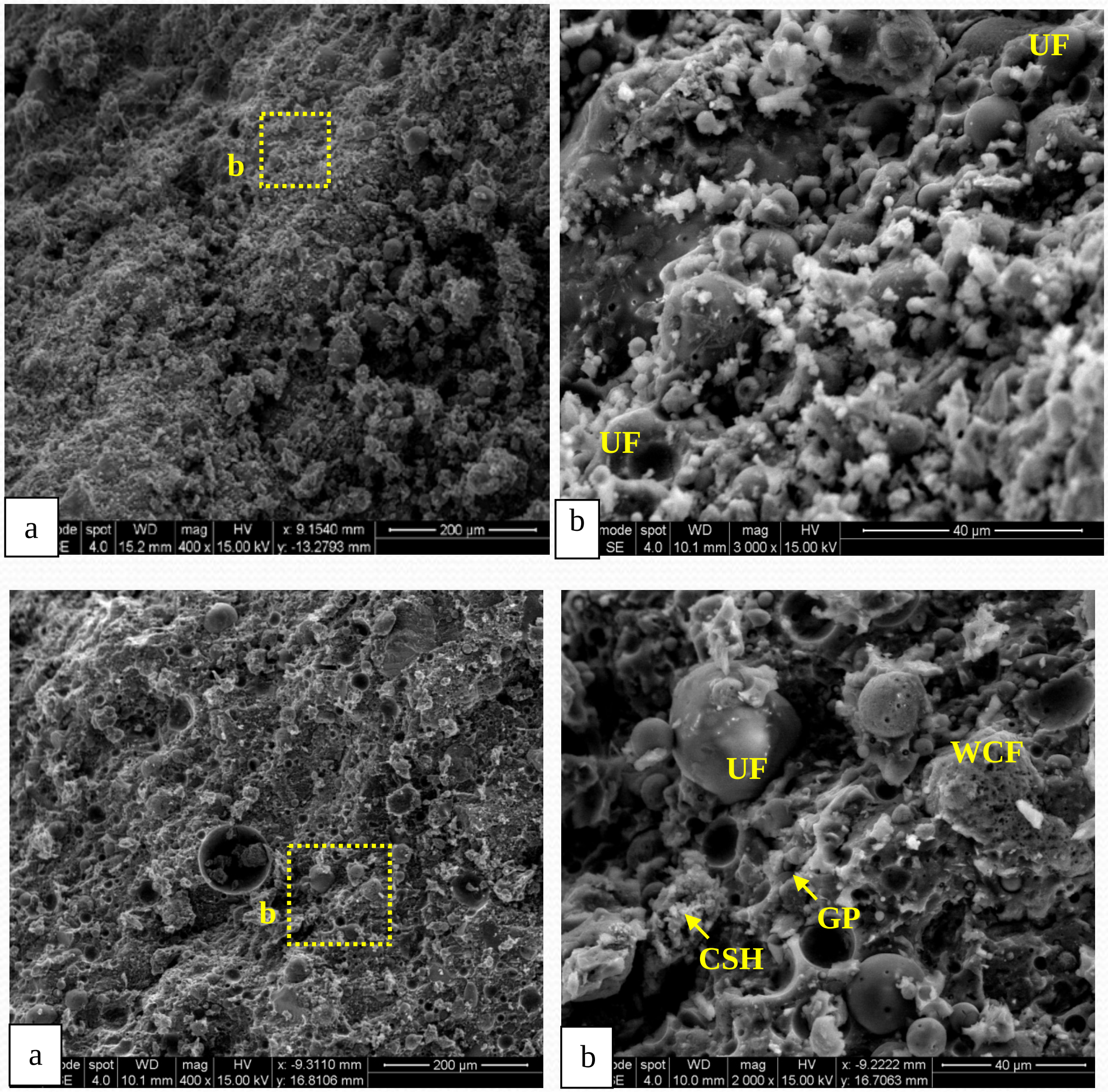
Aqueous Na_2SiO_3

- WCF content: 0, 25, 50, 75 and 100%
- NaOH Concentration: 5M and 10M
- SS/N = 1 and 2

❑ Effect of WCF content on UCS



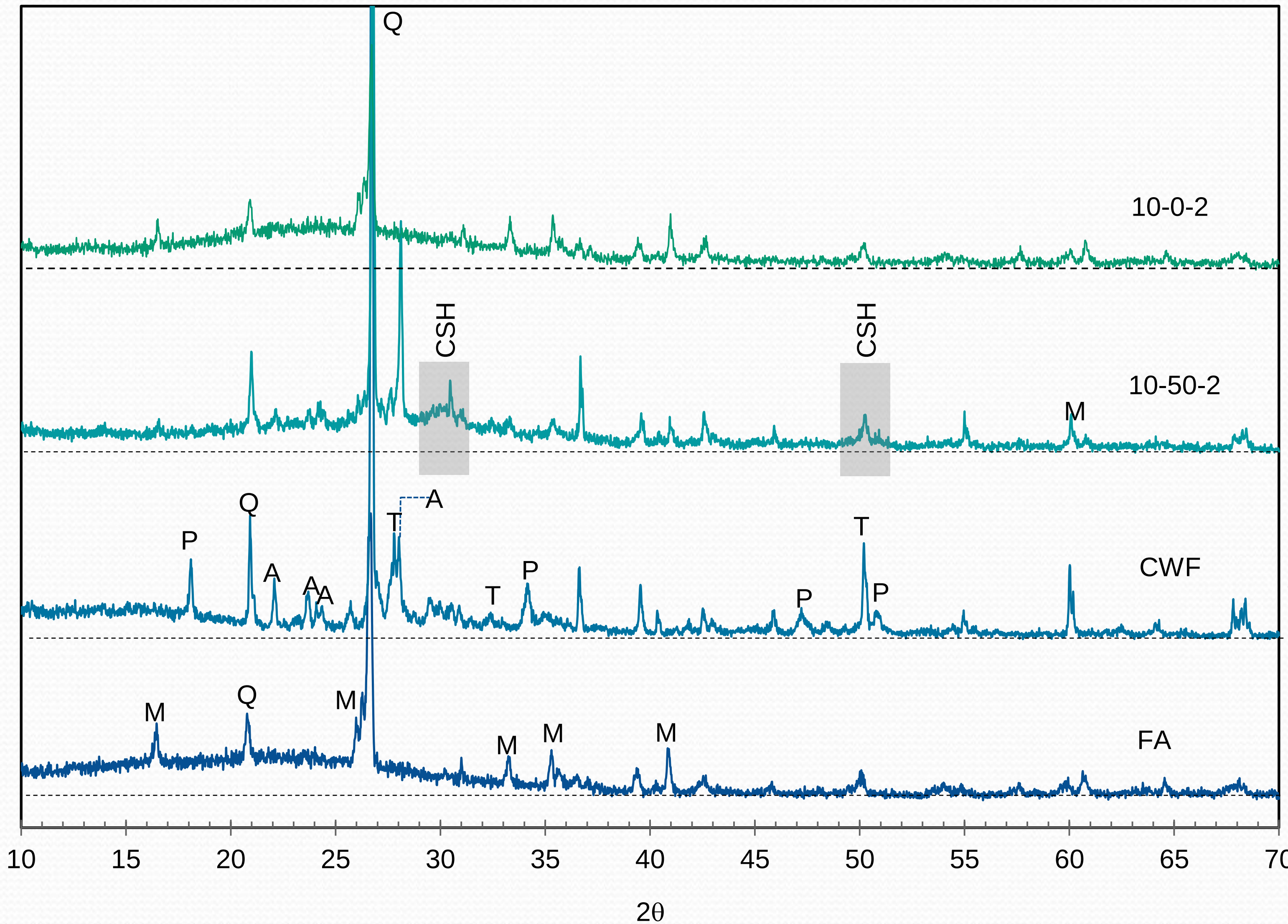
❑ SEM micrographs



0% WCF

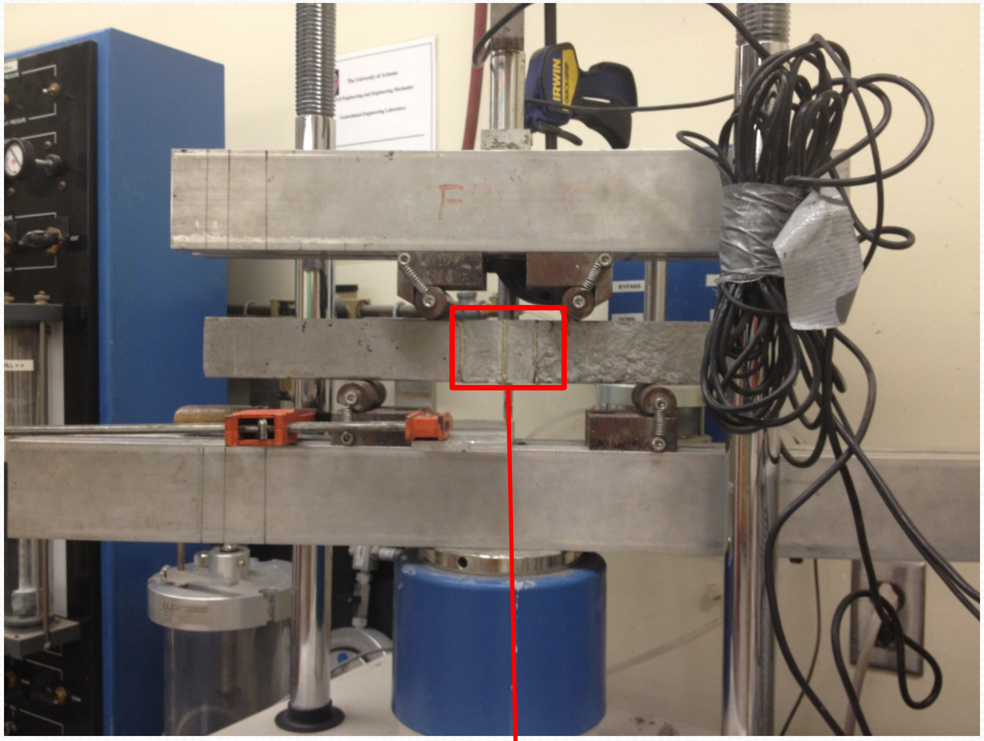
50% WCF

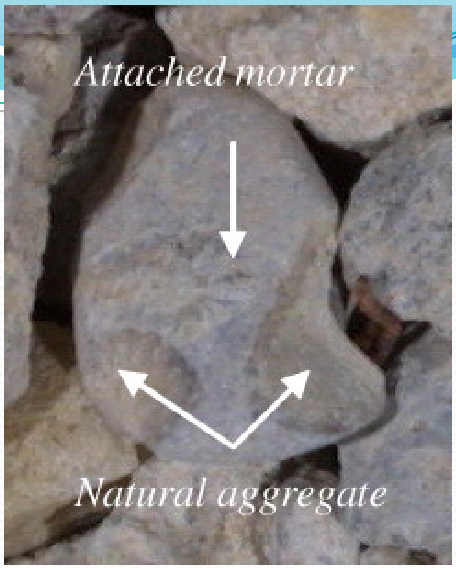
❑ XRD patterns



A: anorthite,
M: mullite,
P: portlandite,
Q: quartz,
T: 1.1-nm tobermorite)

❑ Four-point bending tests

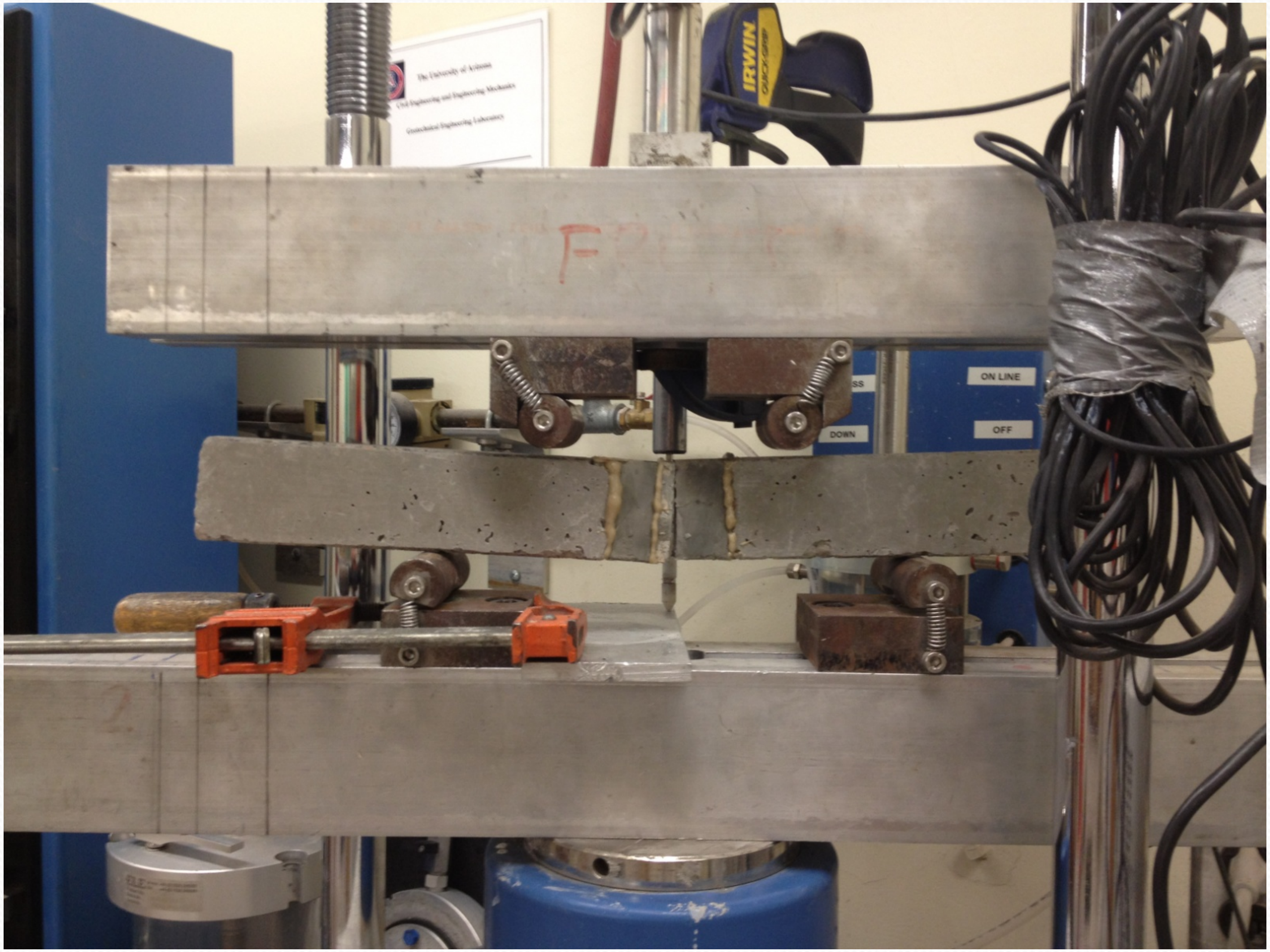




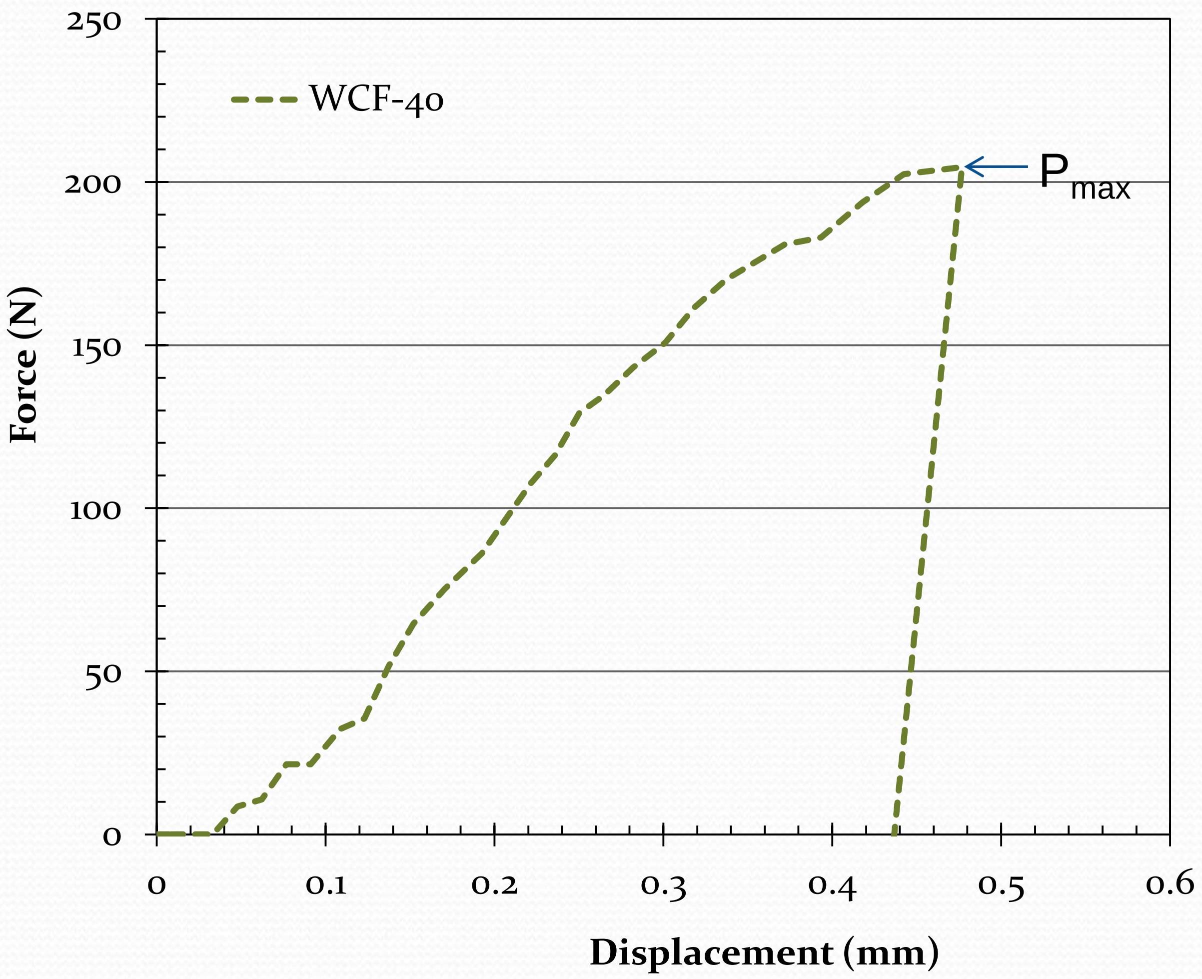
➢NA-paste interface:
- NA: Limestone slice
- Paste: OPC and WCF/FA
- Paste W/S: 0.30, 0.35, 0.40

➢Old paste-paste interface:
- Old paste: Old OPC
- Paste: OPC and WCF/FA
- Paste W/S: 0.30, 0.35, 0.40

❑ Four-point bending tests



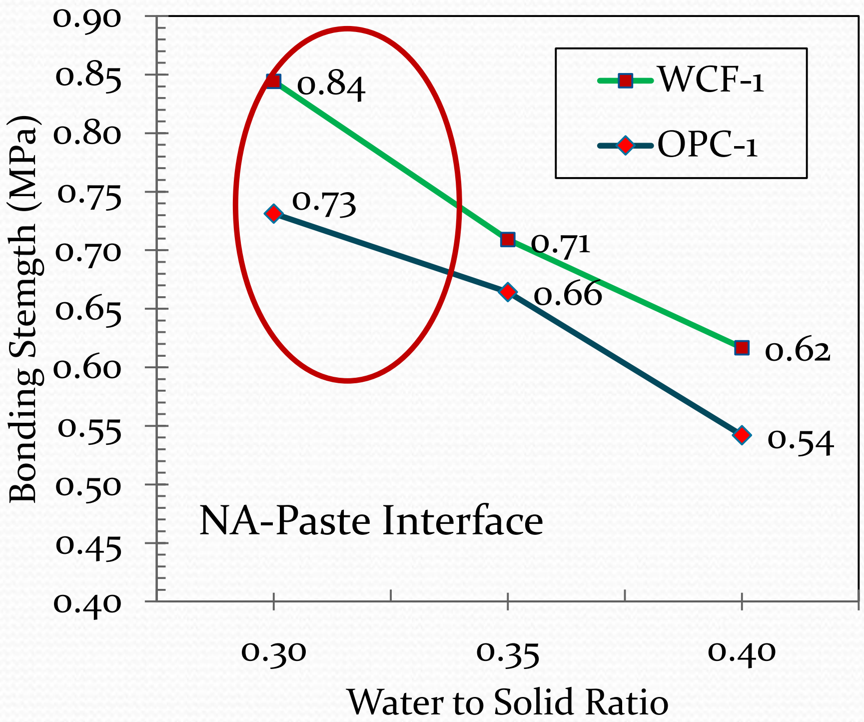
❑ Four-point bending tests

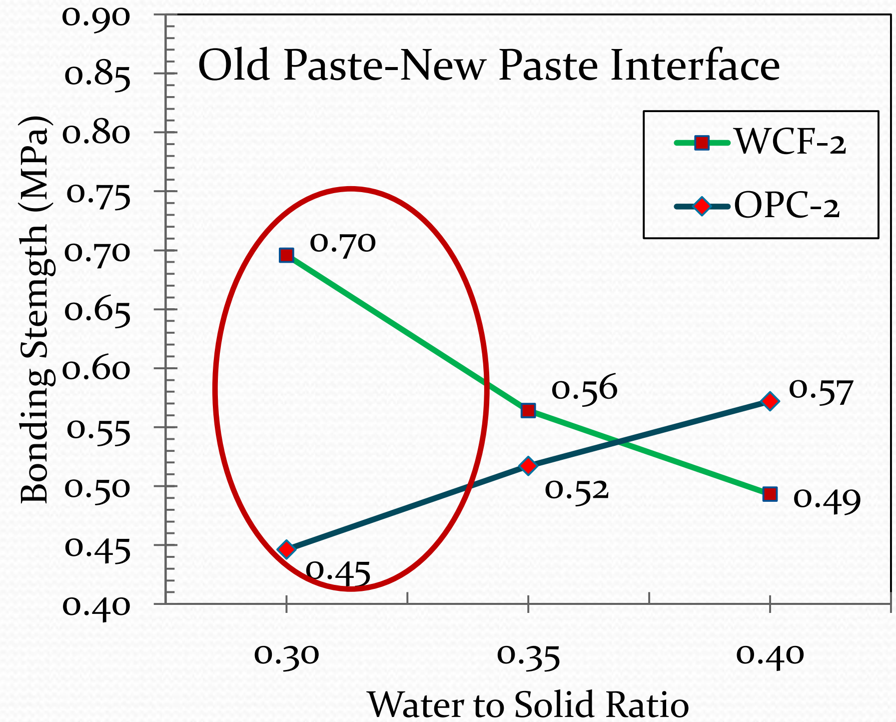


Bonding strength:

$$\sigma_b = \frac{3P_{max}l}{4b(d-a)^2}$$

❑ Four-point bending tests – Test Results

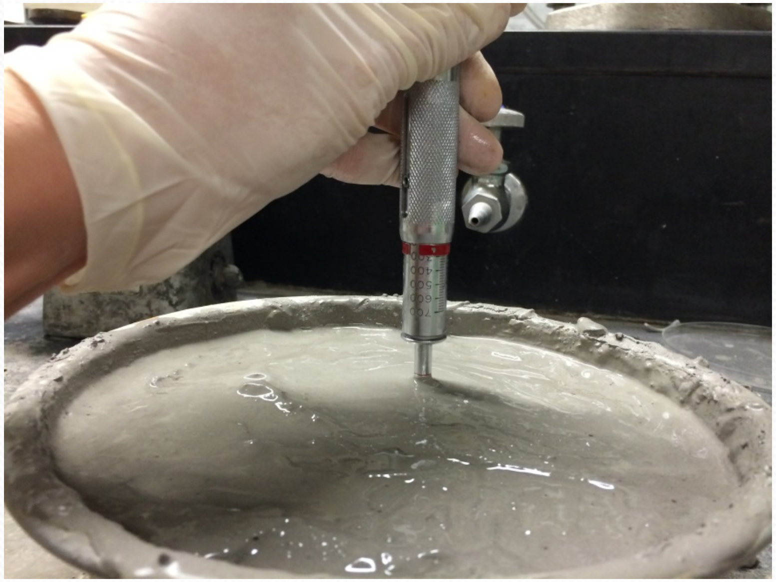




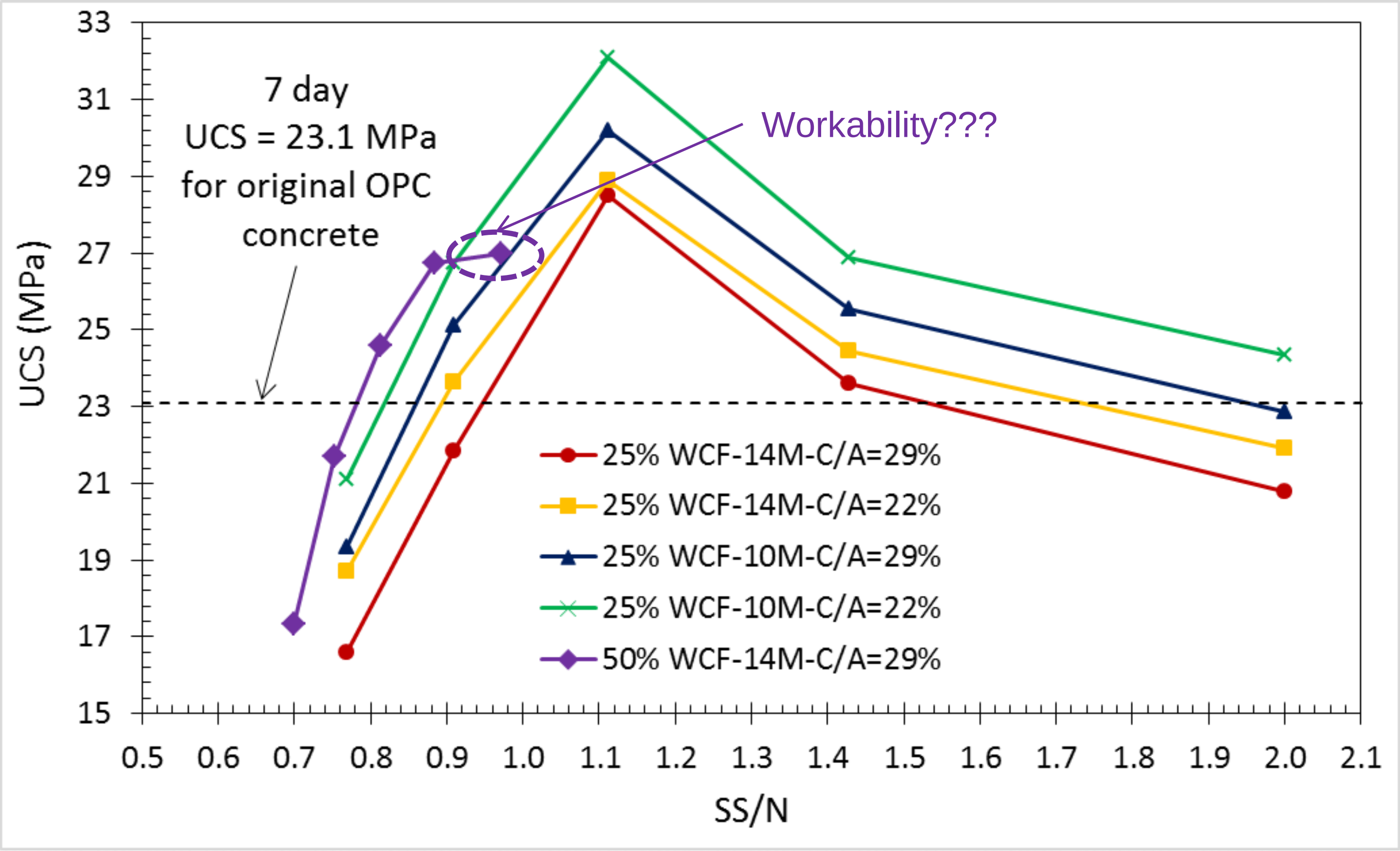
- NA: Does not absorb water
- Old paste: Absorbs water
- OPC paste: Needs water for curing/hydration
- WCF GP paste: Expels water during curing

❑ Tests on geopolymer concrete

- ➢ Setting time
- ➢ UCS



7 day UCS of geopolymer concrete



Outline of Presentation

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

Summary and Conclusions

- Inclusion of WCF improves the UCS of geopolymer binder up to a certain WCF content and further increase of WCF content leads to decrease of UCS. In the current experiment, 50% was found as the optimum WCF content.
- WCF enhances the strength mainly due to the formation of low Ca semi-crystalline CSH gel which coexists with the geopolymer gel.
- The geopolymer paste-NA interface has higher strength than the OPC paste-NA interface; the geopolymer paste-old OPC paste interface also has higher strength than the OPC paste-old OPC paste interface at low water/solid ratio.
- GP concrete using WCF/FA and RCA can have higher strength than the original OPC concrete.

Acknowledgement

➢ Project Participants

Saeed Ahmari, Rui Chen, Xiaobin Ding, Xin Ren, Rasoul Shadnia, Mo Sadat, Lino Manjarrez (Graduate students)

John Lyons, Mark Gregory (Undergraduate students)

➢ Sponsors and Supporters

- National Science Foundation (NSF)
- Environmental Research and Education Foundation (EREF)
- Boral Material Technologies Inc. (providing fly ash samples)
- Salt River Materials Group (providing fly ash samples)
- ADOT (providing testing service)

Thank You!

Lianyang Zhang, PhD, PE
SMART (Sustainable Materials and Recycling Technologies) Laboratory
Department of Civil Engineering and Engineering Mechanics
University of Arizona
(520)-626-0532, lyzhang@email.arizona.edu