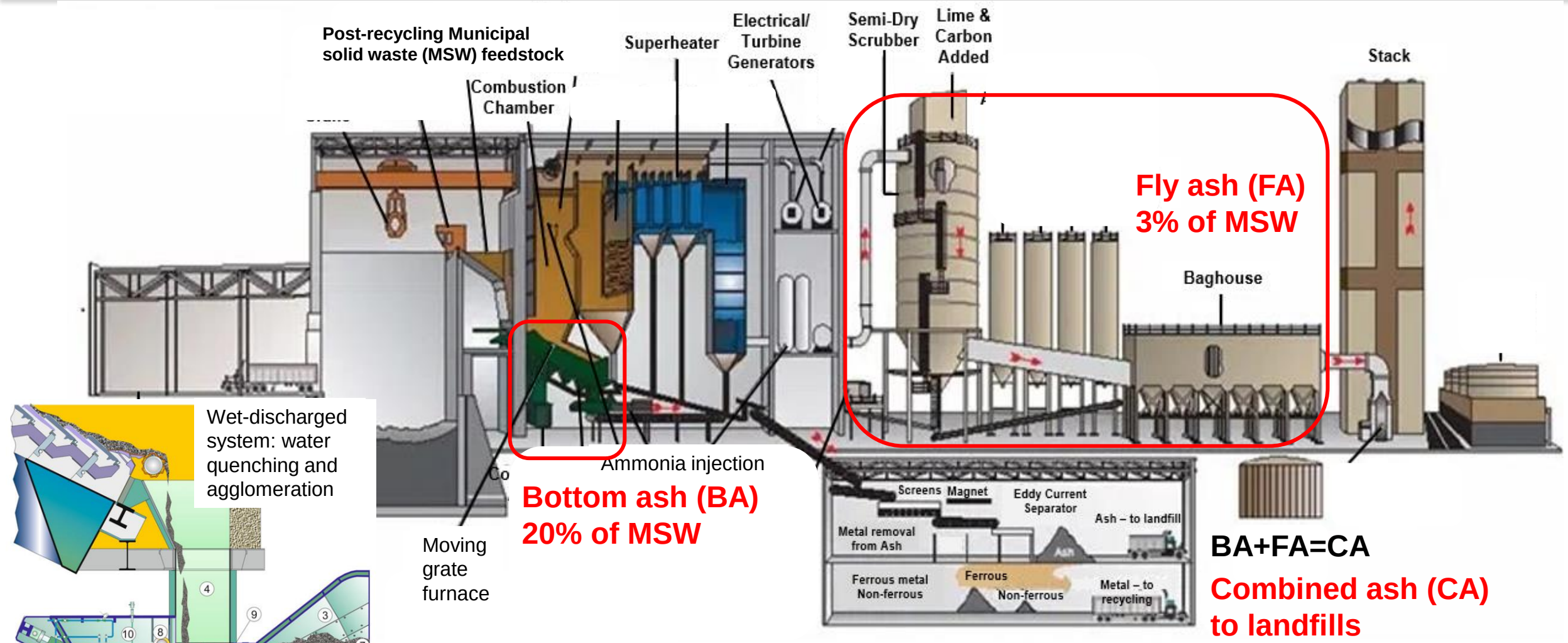
Performance of Structural Concrete Using Waste-to-Energy (WTE) Combined Ash

Yixi Tian, **Postdoc Research Scientist**

Supervisors: Prof. A.C. (Thanos) Bourtsalas, Prof. Shiho Kawashima, Prof. Nickolas J. Themelis,
Earth and Environmental Engineering Department
Civil Engineering and Engineering Mechanics Department
Columbia University

Waste-to-Energy (WTE) Residues Generation



Every year, 30 million tons post-recycling municipal solid waste (MSW) to WTE, generating 7 million tons of WTE residues

Benefits and Challenges: Use of WTE Combined Ash in Concrete

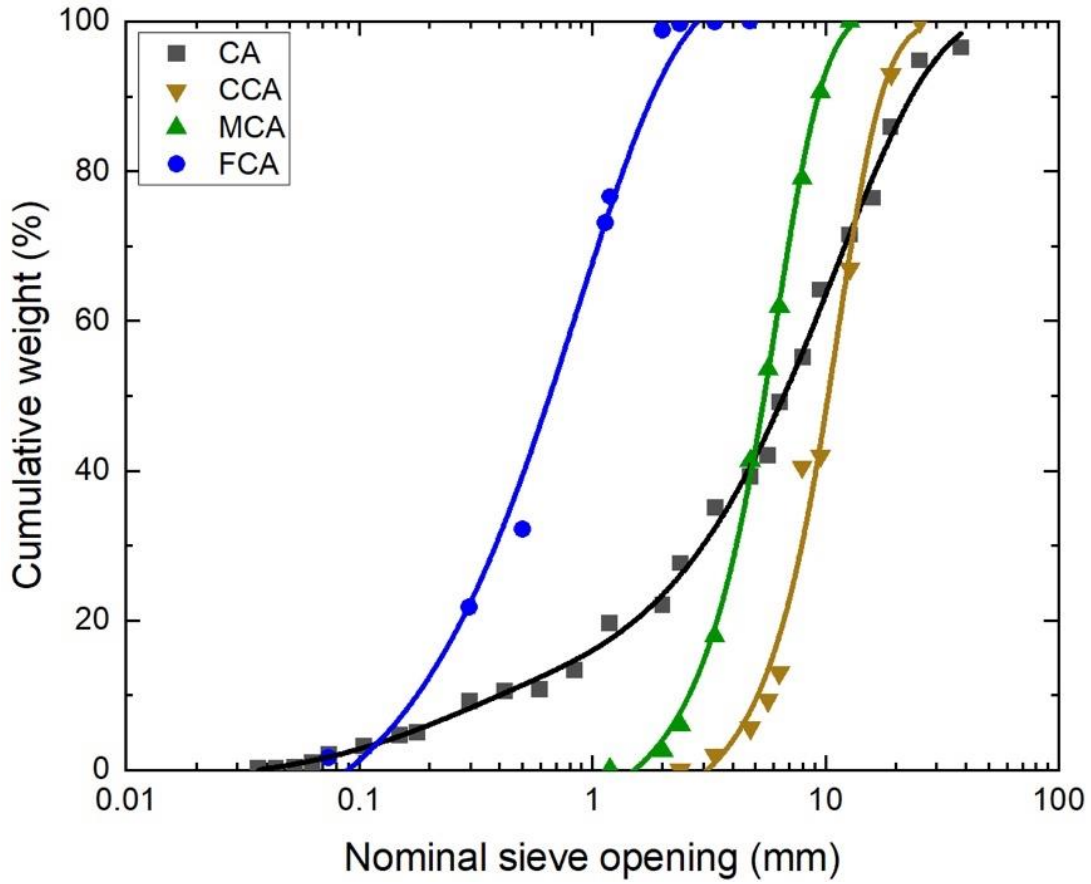
Benefits

- **Circular economy:** Transforming the waste residues to secondary construction materials with effective cement stabilization/solidification.
- **To WTE plants:** Reducing the cost of landfills (MSW: $54/ton; hazardous: $130/ton).
- **To construction**: Reducing the cost of materials and the high environmental impact of natural resource extraction.

Challenges

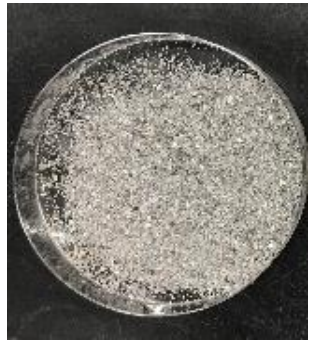
- **Heterogenous materials:** 50-70% mineral fractions, 15-30% glass and ceramics, 5-13% ferrous metals, 2-5% non-ferrous metals, 1-5% unburned organics
- **Low reactivity:** Size separation & selection → for better applications design
- **Leaching**: Examining the leachability of heavy metals in concrete products

Particle Size Distribution of WTE Combined Ash and Ash Fractions



9.5-25 mm
Coarse
(CCA)

2-9.5 mm
Medium
(MCA)



< 2 mm
Fine
(FCA)

Combined ash (CA) undergoes water washing, crushing, and screening to yield three ash fractions: 27% coarse combined ash (CCA, 9.5-25 mm), 37% medium (MCA, 2-9.5 mm), and 25% fine (FCA, < 2 mm) according to ASTM C136 and ASTM C33 for civil engineering applications.

Mix Design of Concrete and Cement Mortar for Three Ash Fractions

Structural concrete

9.5-25 mm
Coarse (CCA)

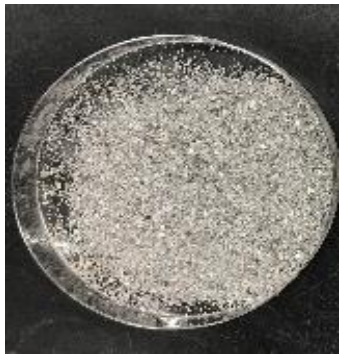
2-9.5 mm
Medium (MCA)

CCA and MCA substitute stone aggregate (crushed gravel)

Sand : total aggregate : cement = 1.67 : 2.31 : 1.

CCA or MCA to gravel replacements: 0, 10, 30, 100 wt.%

Cement mortar



< 2 mm
Fine (FCA)

The ratio of fine aggregate to cement was fixed at 3:2.

1. Directly using FCA as sand substitute

w/c = 0.4, 0.5 0, 10, 25, 50, 75, 100 vol.%

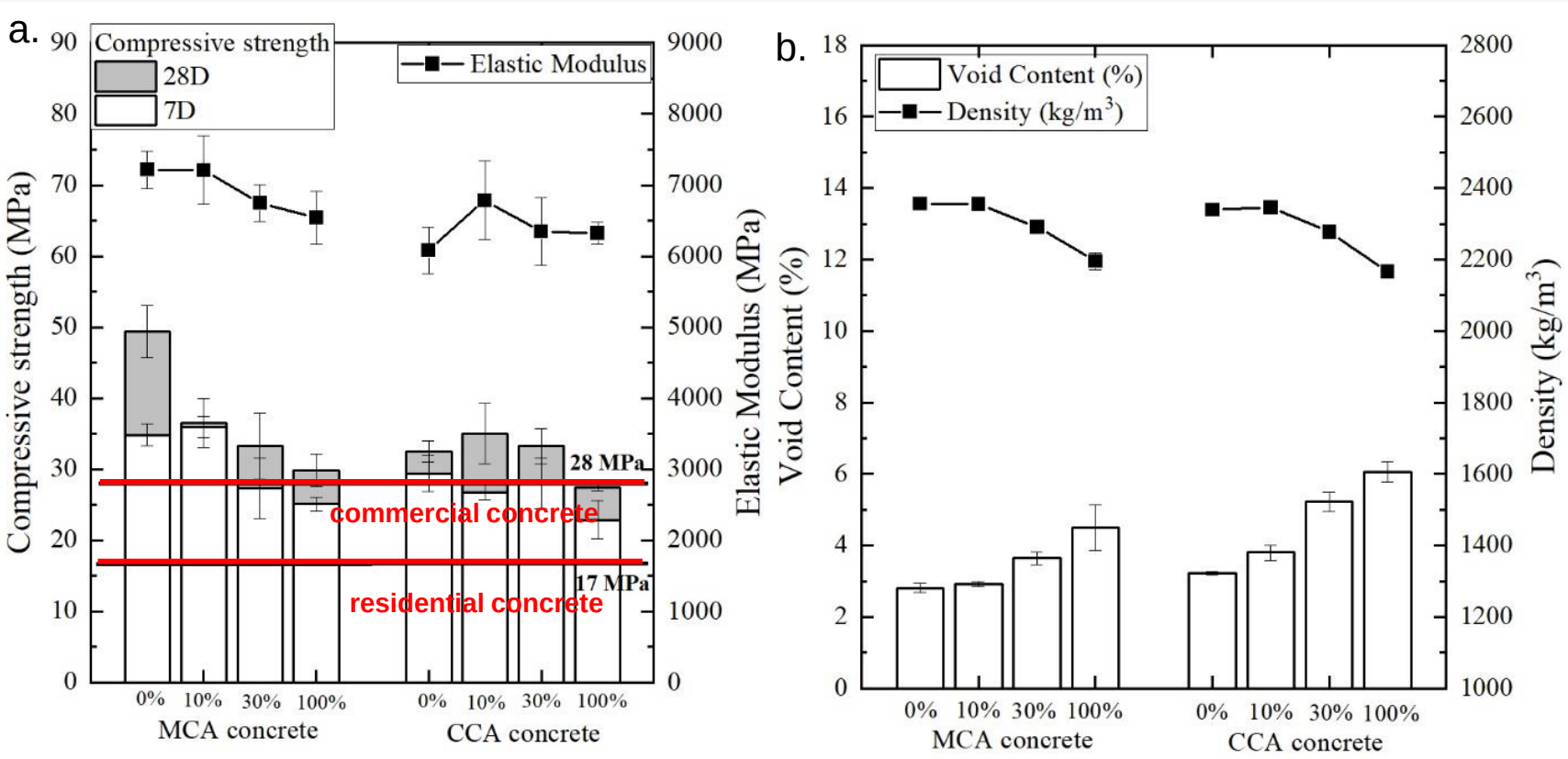
2. Milling the FCA to powder (MFCA) and using it as cement substitute

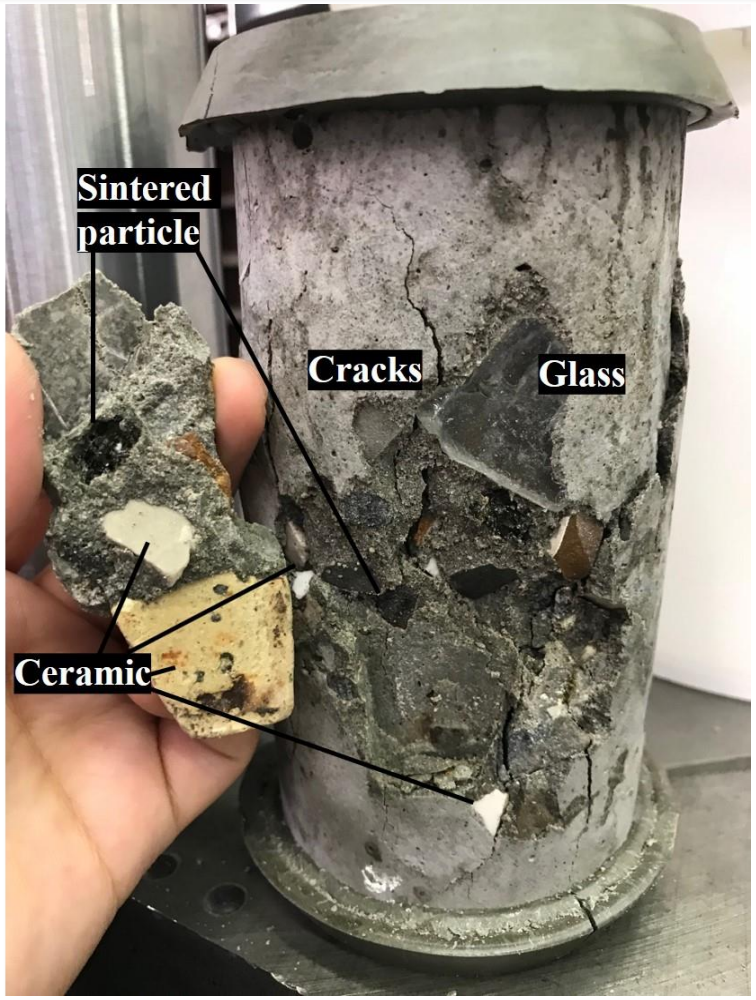
w/c = 0.4 0, 10, 25, 50 vol.%

Research Outline: Use of WTE Combined Ash in Concrete

- **Methods**
  - **Concretes (CCA, MCA):**
    - **Compressive strength gain, elastic modulus, density, void content**
  - **Mortars (FCA, MFCA):**
    - **Compressive strength gain, flow table, XRD, SEM**
  - **Leachability**
- **Conclusions and future work**

Coarse and Medium Ash as Stone Aggregate Substitutes in Concrete

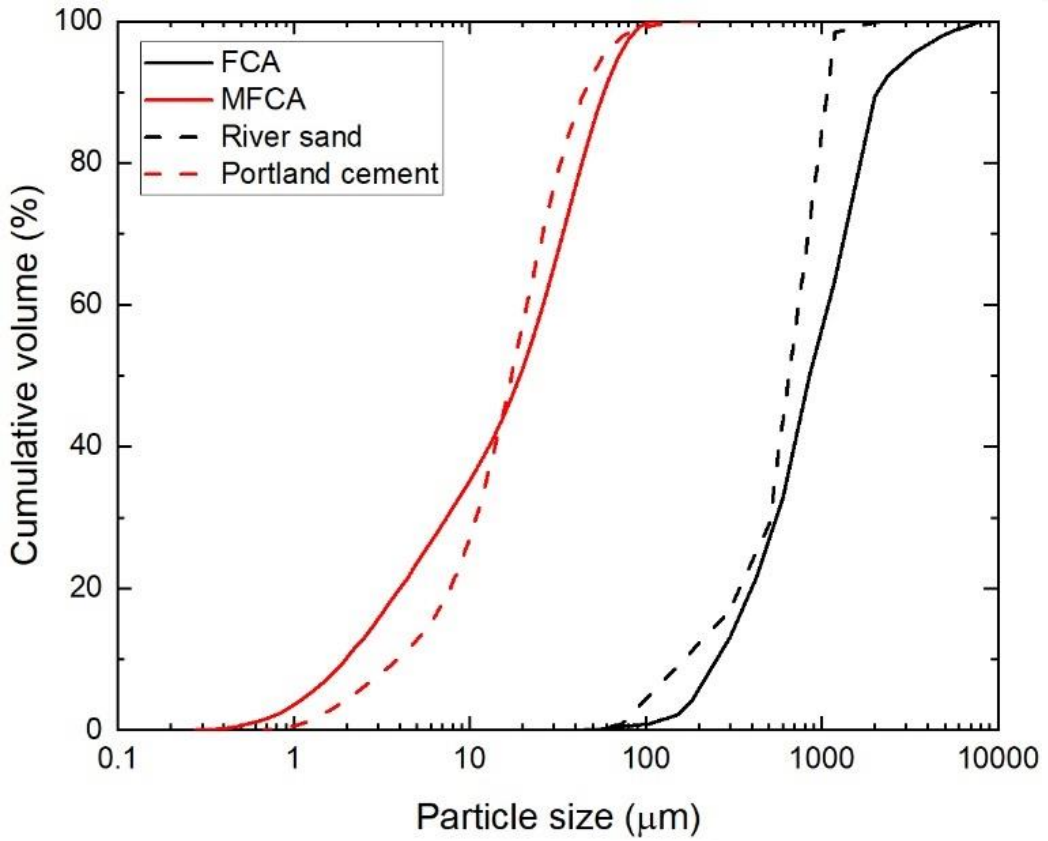


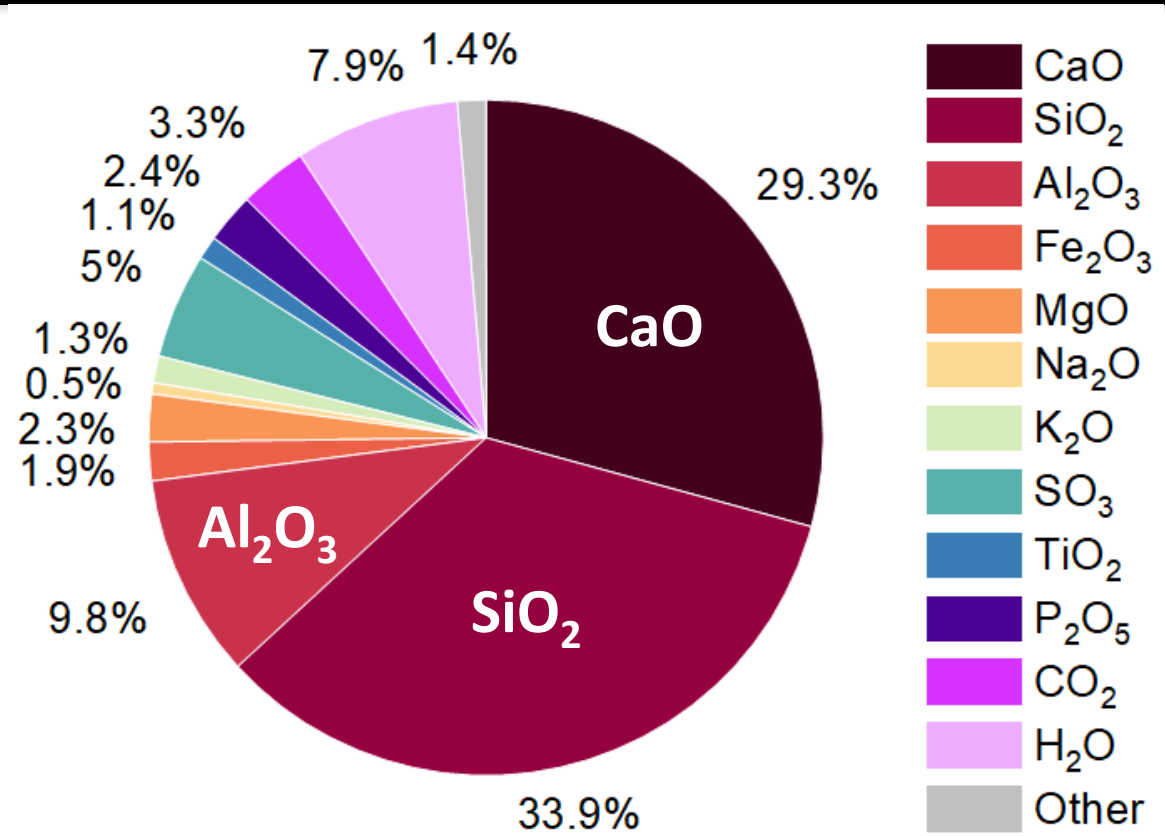


Fractured surface of CCA 100% concrete

- **Up to 100 wt.% of stone aggregate in concrete can be substituted by MCA and CCA.**
- **The 28-day compressive strength exceeds 28 MPa, which is comparable to commercial concrete.**

Characterization of Fine Combined Ash for Applications Design

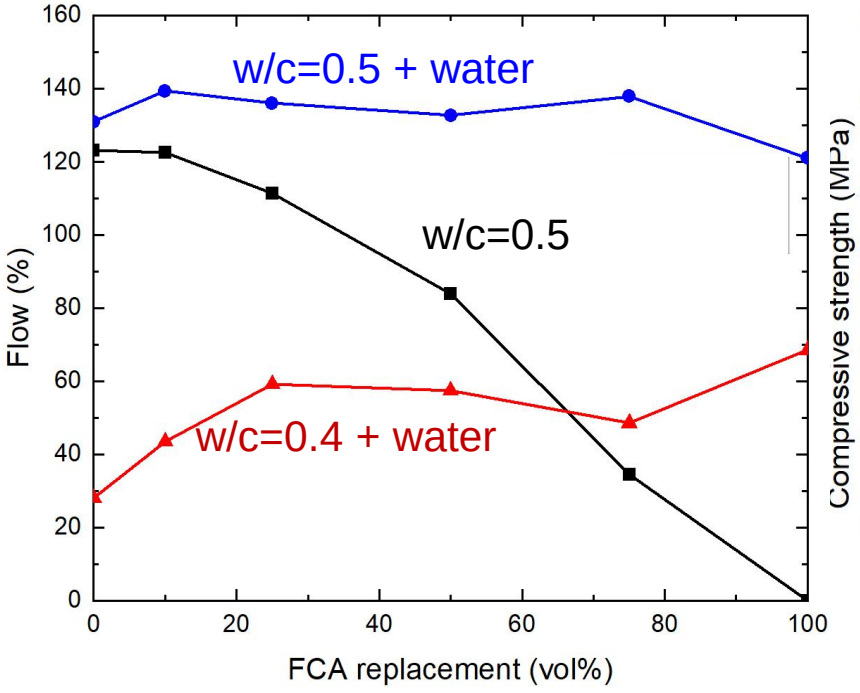


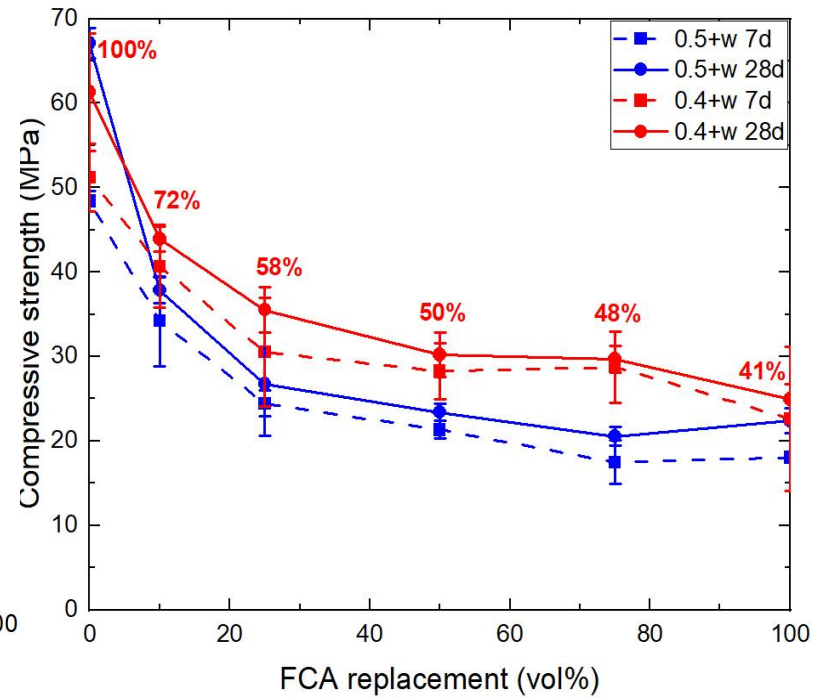


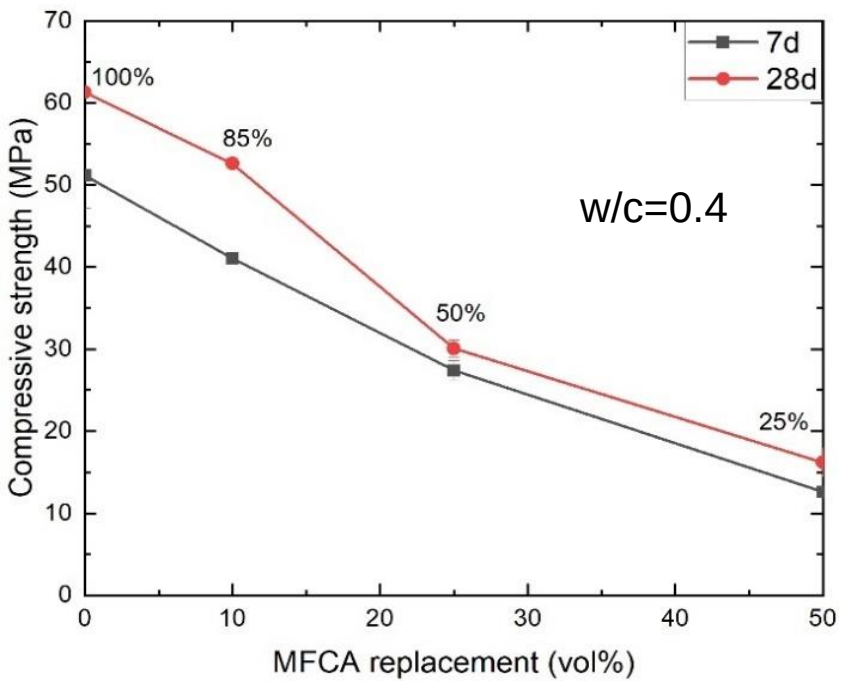
- **When FCA is utilized as a sand substitute, it was considered to have no additional cementitious or pozzolanic reactivity.**
- **Utilizing MFCA as cement substitute, the particle size was reduced increasing the relative surface area, resulting in an influence on cement hydration reaction.**

Fine Ash as Sand Substitute or Cement Substitute in Cement Mortar

Compensating for high water absorption of FCA (12.80%) to improve workability when utilizing it as aggregate replacement

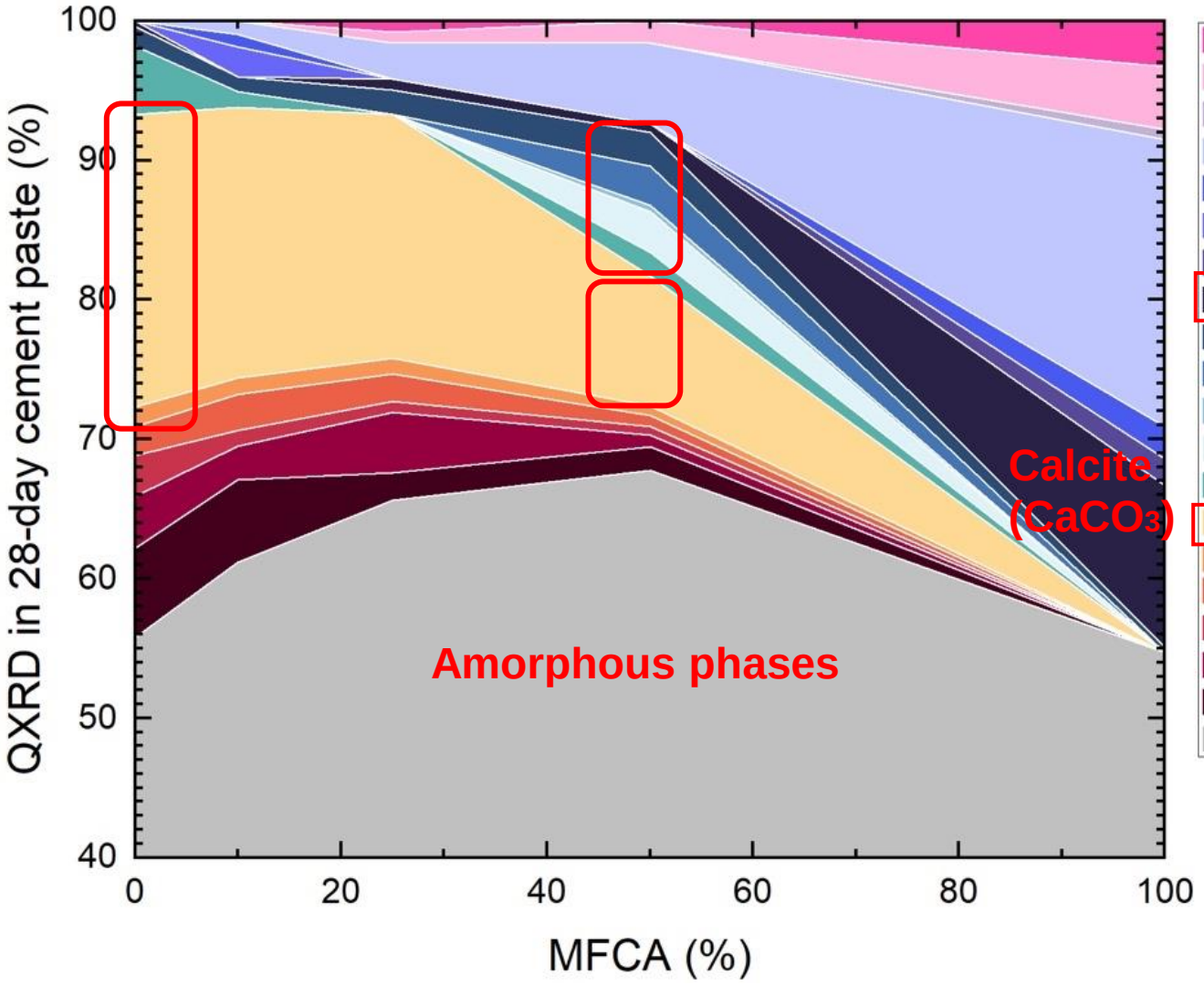






- **When utilizing FCA as a sand substitute, additional water is critical for maintaining proper consistency and workability.**
- **To achieve a 28d compressive strength of > 28 MPa, sand replacement with FCA must be limited to 50 vol.% and OPC replacement with MFCA must be limited to 25 vol.%.**

Mineral Transformation of the Milled Fine Ash in Cement Paste



- Akermanite $Ca_2Mg(Si_2O_7)$
- Gehlenite $Ca_2Al[AlSiO_7]$
- Cristobalite SiO_2
- Quartz SiO_2
- Rutile TiO_2
- Syngenite $K_2Ca(SO_4)_2 \cdot H_2O$
- Anhydrite $CaSO_4$
- Calcite $CaCO_3$
- Hemicarboaluminate $Ca_4Al_2(CO_3)_{0.5}(OH)_{13} \cdot 5.5H_2O$
- Monocarbonate $Ca_4Al_2(CO_3)(OH)_{12} \cdot 5H_2O$
- Monosulfoaluminate $Ca_4Al_2(SO_4)(OH)_{12} \cdot 6H_2O$
- Hydrocalumite $Ca_2Al(OH)_{6.5}Cl_{0.5} \cdot 3H_2O$
- Ettringite $Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$
- Portlandite $Ca(OH)_2$
- Periclase MgO
- Tetracalcium aluminoferrite/C_4AF $Ca_4Al_2Fe_2O_{10}$
- Tricalcium aluminate/C_3A $Ca_3Al_2O_6$
- Belite/C_2S Ca_2SiO_4
- Alite/C_3S Ca_3SiO_5
- Amorphous phases

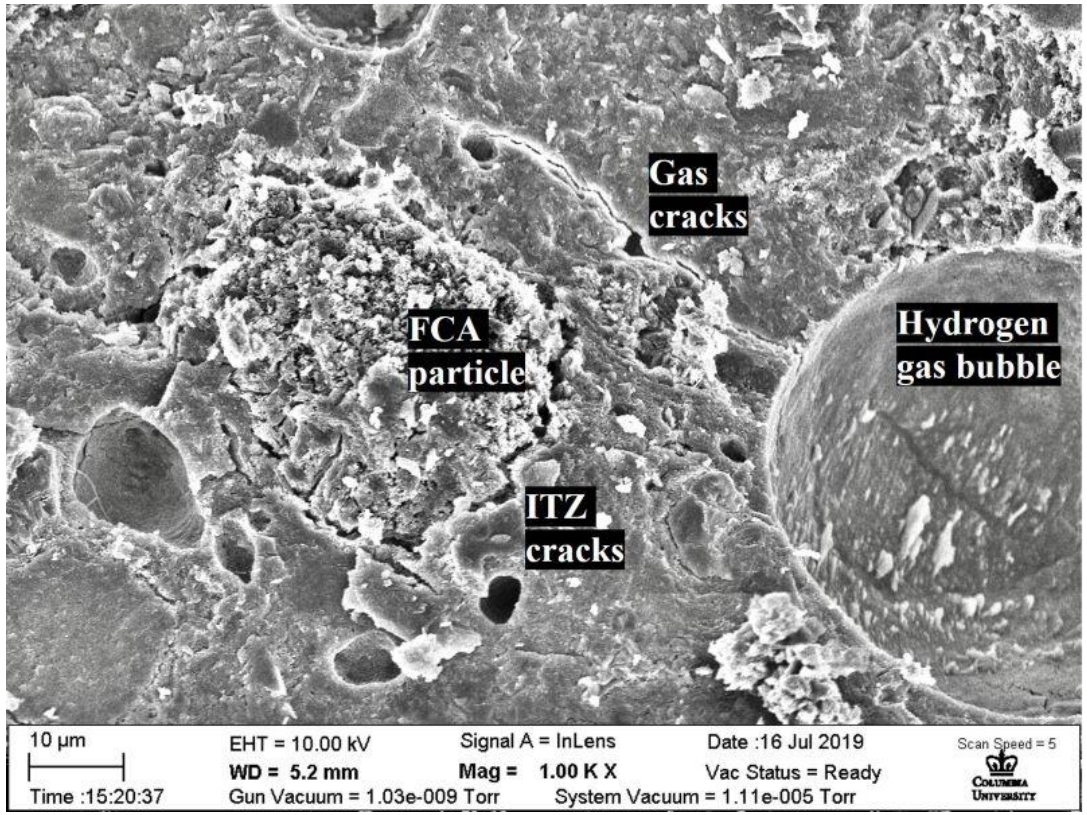
Cement paste for XRD quantification analysis w/c = 0.4

1. **MFCA contributes to the formation of more amorphous phases due to pozzolanic reaction.**

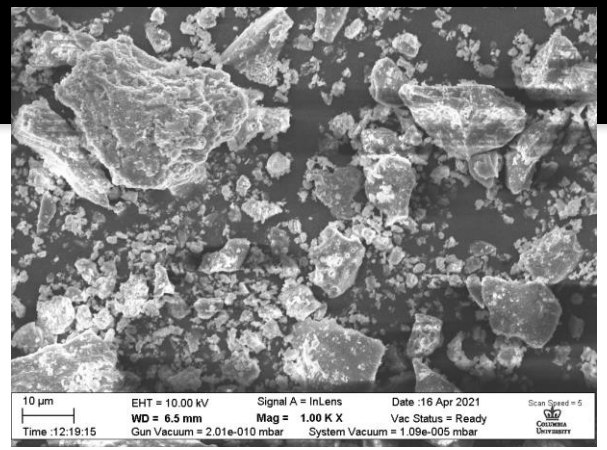
2. MFCA reaction with cement hydration products resulted in the transformation of calcite.

SEM of Derived Products

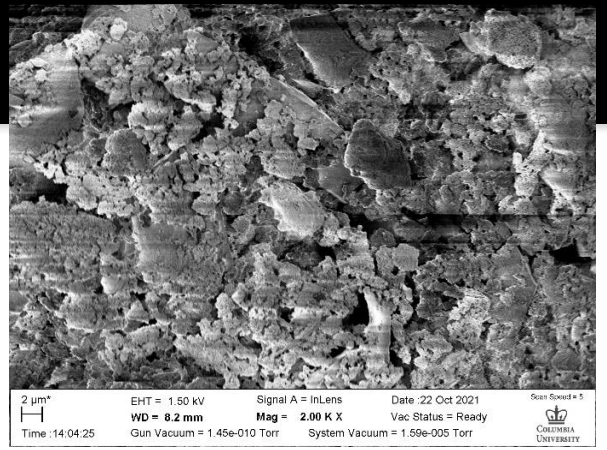
Fracture surface of 28d 100 vol.% FCA cement mortar



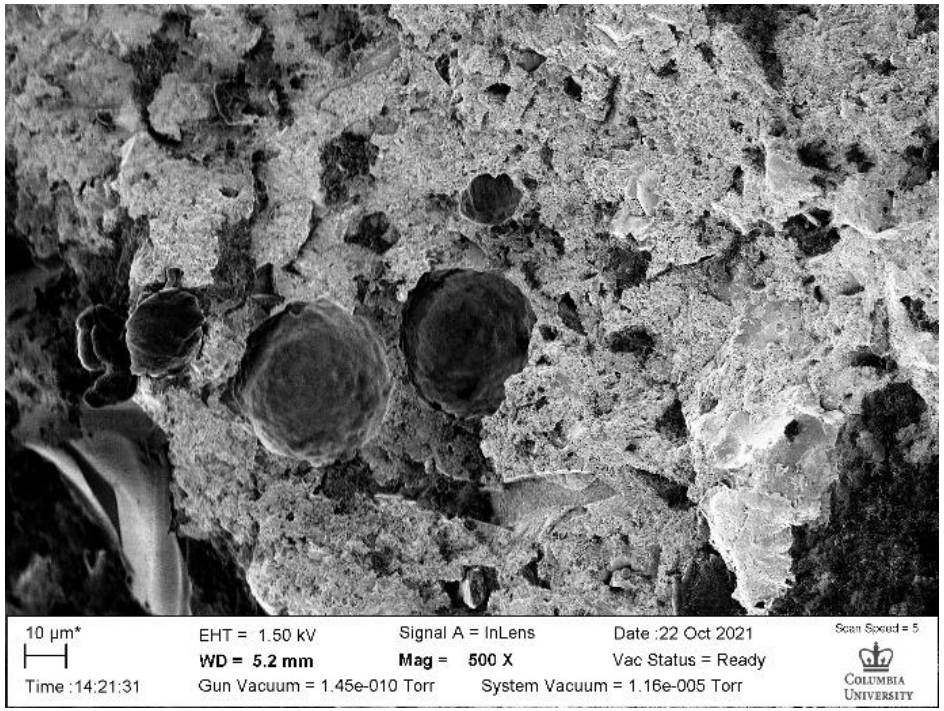
Metallic aluminum (Al) in FCA/MFCA reacted with $Ca(OH)_2$, generating hydrogen gas bubbles and cracks.



MFCA particles



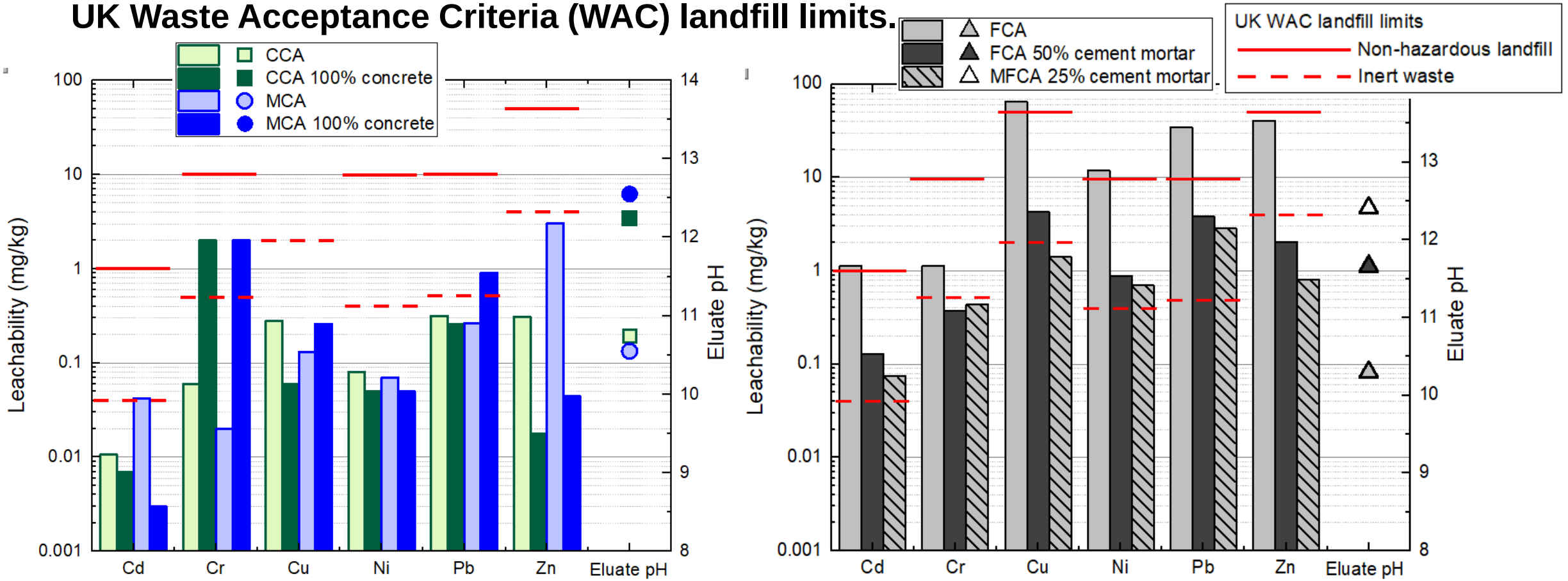
MFCA paste



28d 50 vol.% MFCA cement paste

Effective Cement Stabilization/Solidification of Three Ash Fractions

Leachability (mg/kg) of heavy metals of ash vs. derived mortar/concrete, compared to UK Waste Acceptance Criteria (WAC) landfill limits.



Introducing CCA or MCA to concrete and FCA to cement mortars can effectively stabilize/solidify the heavy metals and transform the three ash fractions to non-hazardous or inert material that can be used in construction.

Summary of Conclusions and Future Works

Summary of Conclusions:

- **Up to 100% normal aggregate can be substituted with 2-25 mm WTE combined ash (MCA, CCA) and still exhibit 28-day compressive strengths > 28MPa.**
- **To achieve a 28-day compressive strength of > 28 MPa, sand replacement with FCA must be limited to 50 vol.% and OPC replacement with MFCA must be limited to 25 vol.%.**
- **The MFCA contributed to the presence of more amorphous phases through pozzolanic reaction.**
- **Utilizing WTE combined ash in concrete can effectively stabilize/solidify the leachability of heavy metals.**

Future work:

- **Comparison of WTE fly ash/bottom ash (different sizes) and coal fly ash/bottom ash (different sizes) in mineral transformation and cementitious reactivity.**

Acknowledgements

Columbia University in the City of New York
COLUMBIA | ENGINEERING
Robert A. W. Carleton Strength of Materials Laboratory

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Thank you ! Any questions ?

Yixi Tian <yt2532@columbia.edu>