Developing Mix Proportions of Class C Fly Ash Based Alkali-Activated Mortar in View of Different 3D-Printing Approaches

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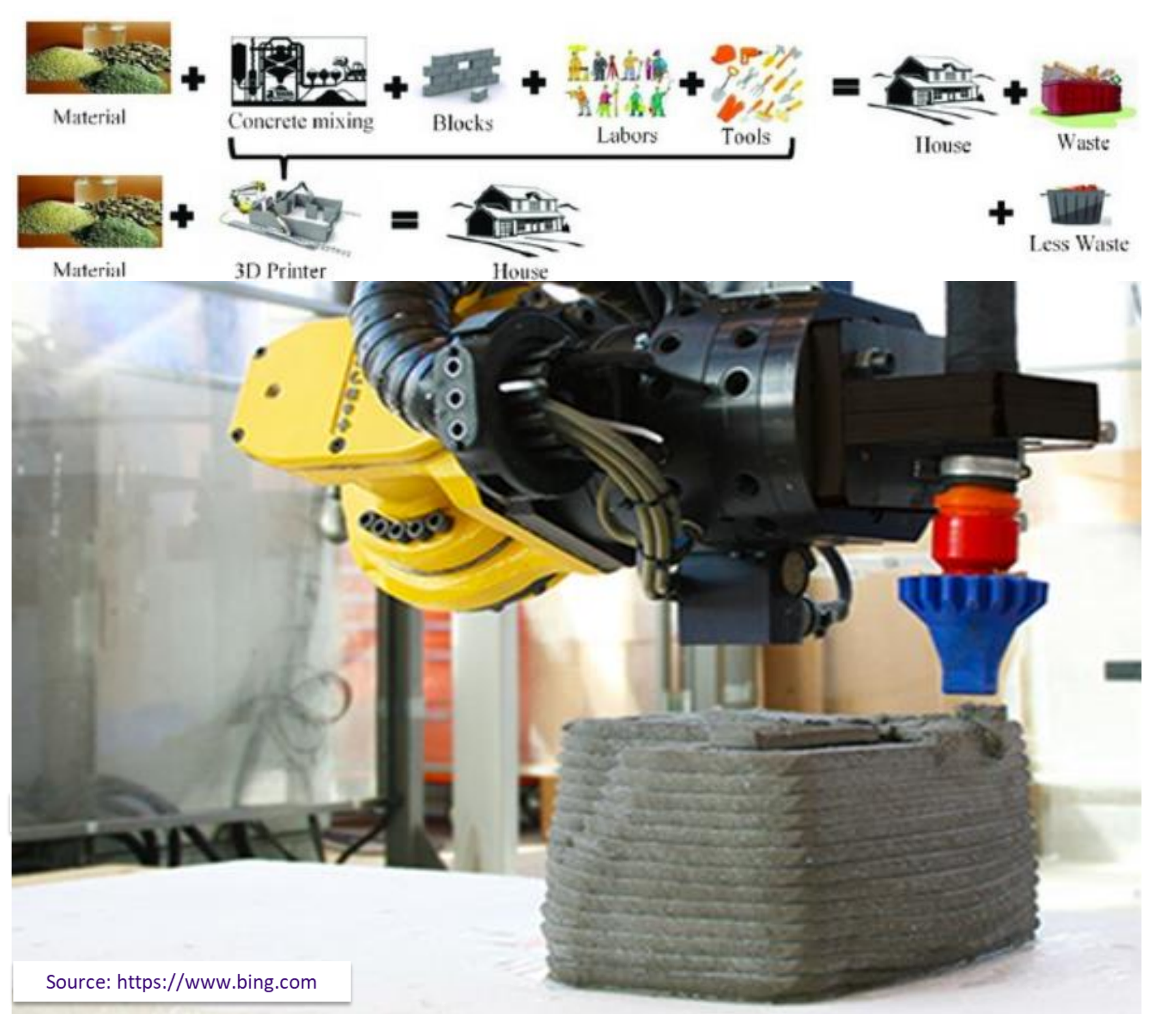
Motivation

- **3-Dimensional printed concrete (3DPC)**
  - Environmentally friendly
  - Design flexibility
  - Cost effective
  - Rapid application



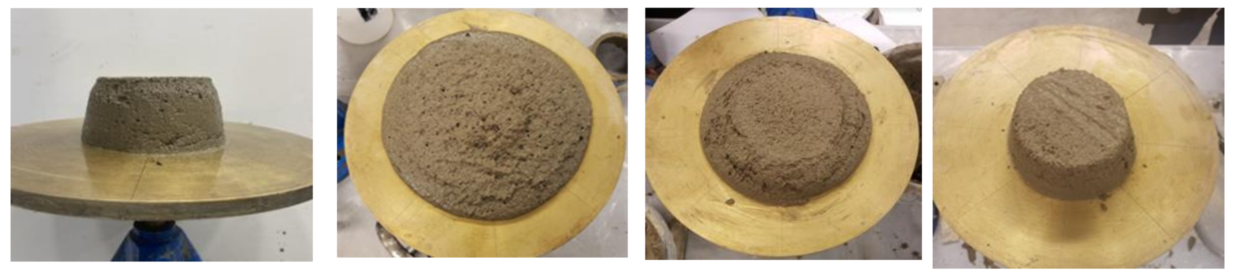
- Approximately 750 million tones of fly ash (FA, a by-product generated when burning coal in power plants) is generated annually in the world.
- Missouri is the fourth largest coal consumer in the U.S. and generates approximately 2.7 million tons of coal combustion residuals annually. 50% of this FA goes to landfills and ash ponds which may trigger environmental risks and safety hazard.
- In this study, FA is used as a main precursor to produce alkali activated mortar (AAM) where 100% of the cement is replaced with fly ash and alkali activators for 3DPC applications.

Objective

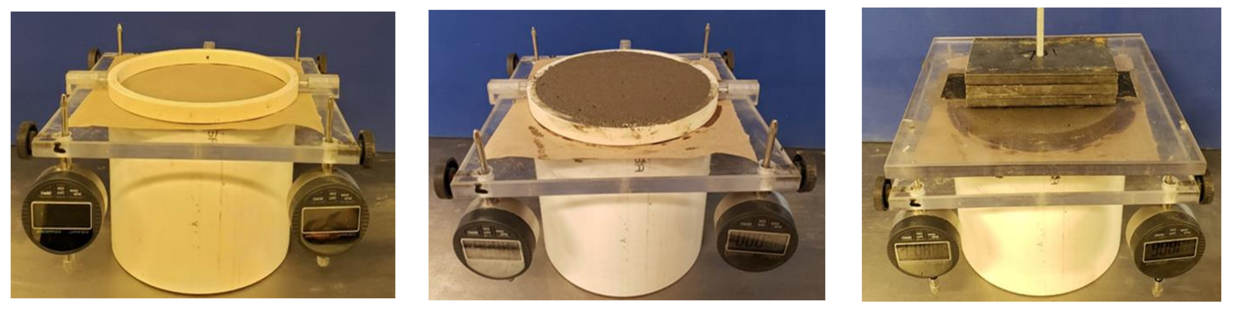
- Develop a wide range of mix proportions of class C FA for different 3DPC approaches including:
  - Mixing a large single batch.
  - Mixing continuously where mixing and printing will be at the same time.
  - Set on demand where the materials could be mixing at the print head and printing immediately without using pumping system.

Experimental Work

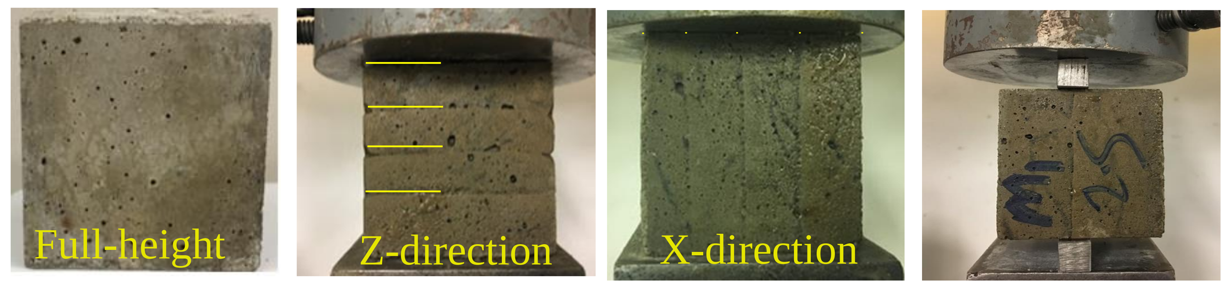
- **Materials**
  - Class C FA as the precursor sourced from Labadie power plant located in Missouri State.
  - Sodium silicate (SS) and sodium hydroxide (SH) were used as the alkaline activators (Alk) with 10 molarity.
  - River sand was used as fine aggregate with a maximum particle size of 1.18 mm.
  - Water to FA (W/FA), alkaline activators to FA, SS/SH ranged from 0.36-0.40, 0.250-0.300, and 0.5-2.0, respectively.
- **Lab Tests**
  - Open time (OT) where the AAM could be extruded, and initial setting time (IST) were conducted to evaluate extrudability.
  - Axial deformation and static yield stress using deformation test set up and penetrometer, respectively, were conducted to evaluate buildability.
  - Cycle time (CT) which is the time between adding subsequent layers, ranged from 1.0 to 60 minutes to offer wide range of options for 3DPC applications.
  - The mechanical properties including compressive strength and splitting tensile strength were studied with different CTs.



Open time (OT)



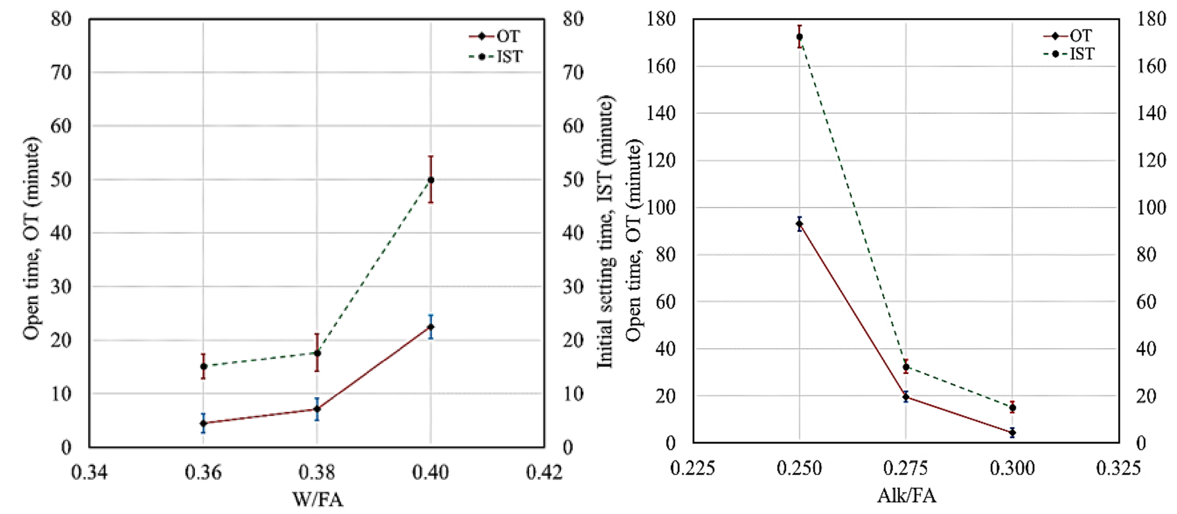
Axial deformation with different cycle time (CT)



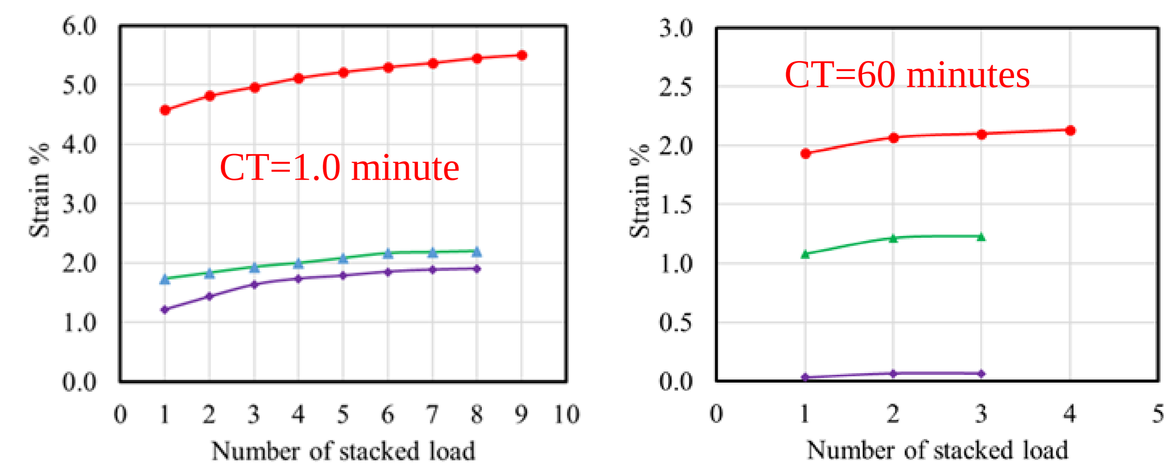
Compressive strength   Splitting tensile

Results

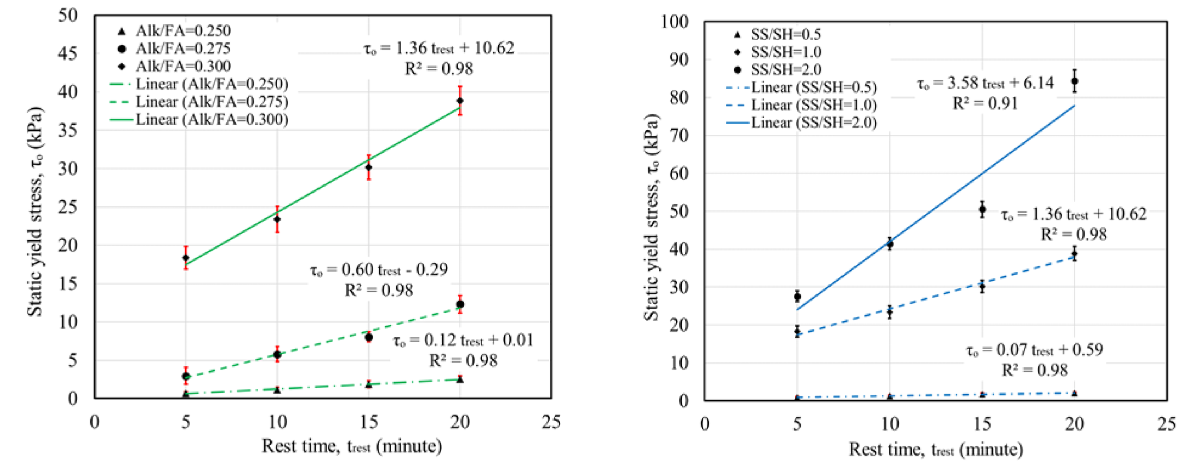
- **Open time (OT) and initial setting time (IST)**
  - OT ranged from 2.5 to 93 minutes.
  - IST ranged from 15 to 172 minutes.



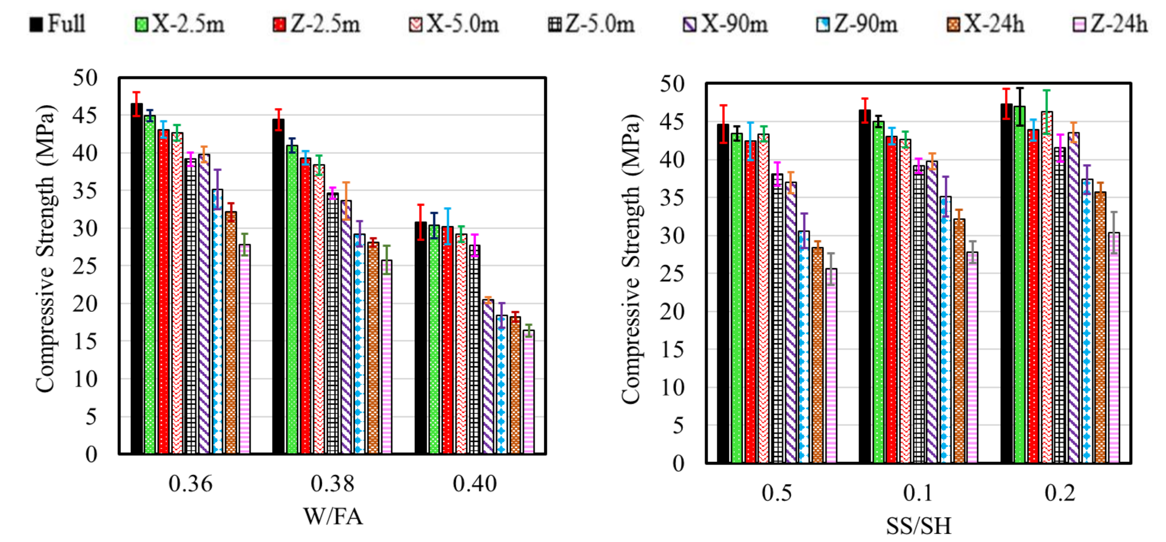
- **Axial deformation with different CTs**
  - Strain ranged from approximately 0.11 to 5.5 % with CT ranging from 1.0 to 60 minutes.



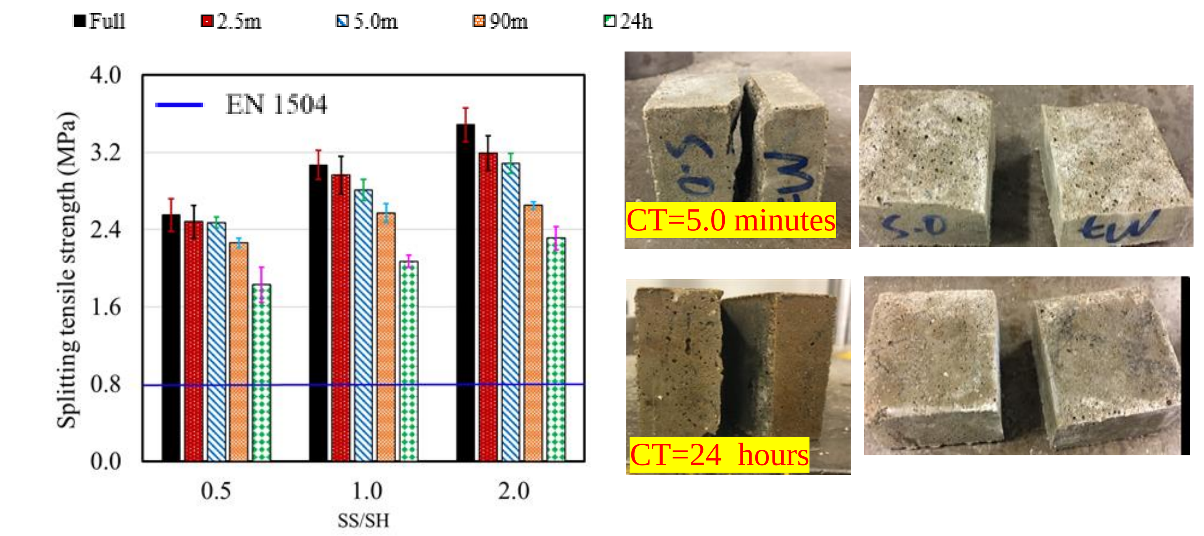
- **Static yield stress evolution with rest time**
  - Static yield stress evolution rate ranged from 0.07 to 3.58 kPa/min.



- **Compressive strength with different CTs**
  - Compressive strength of full-height specimens was higher by 0.3-40 % than 3DPC specimens tested in Z and X directions.



- **Splitting tensile strength and failure mode**
  - The splitting tensile strength of 3DPC specimens exceeded the minimum bond strength of 0.8 MPa recommended by European Standard (EN1504).



Discussion and Conclusion

- Based on the open time (OT), static yield stress evolution rate , cycle time (CT), compressive and splitting tensile strengths, full database was developed for different 3DPC approaches.
- Mixing a large single batch approach could be used for those AAMs having relatively long OT, i.e., more than 30 minutes and low static yield stress evolution rate, i.e., 0.07 kPa/min.
- Mixing continuously or set on demand approaches may present the best option for those AAMs having short OT, i.e., less than 5.0 minutes and rapid static yield stress evolution rate, i.e., 3.58 kPa/min.
- These suggested 3DPC approaches provide flexibility to the industry to adopt the AAM mixture and select the 3DPC approach that best fits a particular structure rather than using either a single AAM mixture or the same 3DPC approach for every task.