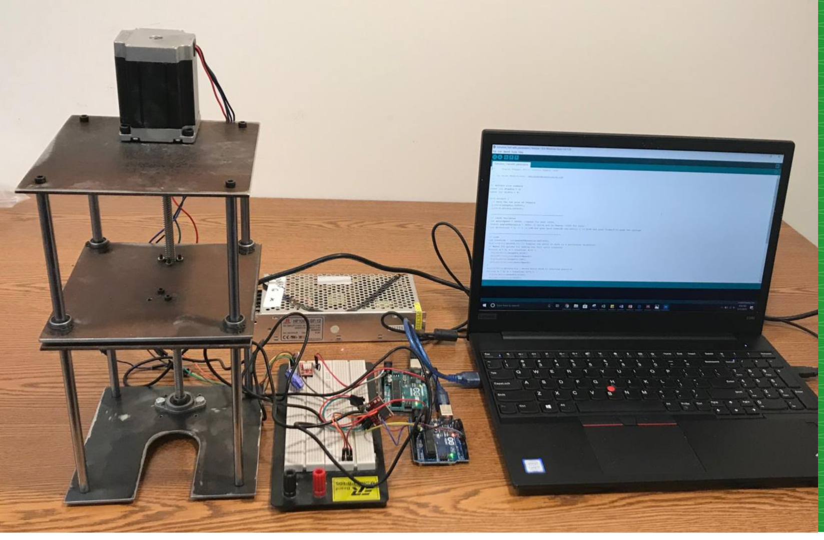


Development of Test Methods for Characterizing Extrudability of Cement-Based Materials for Use in 3D Printing

Jonathan Kuchem - CArE Department – Missouri S&T
Adviser- Dr. Nicolas Libre

Introduction

3D Printing concrete is an upcoming technology that has the opportunity to completely revolutionize the construction industry [1]. It has the potential to decrease construction cost and time, improve environmental aspects of concrete, and provide for optimized structural designs [2]. There are many areas of 3D Printing concrete that need to be defined before widespread implementation from the printing process, geometry, fresh properties, hardened properties, reinforcement, and durability [3,4]. Extrusion will be studied as it is the first process in printing and has not been studied extensively.

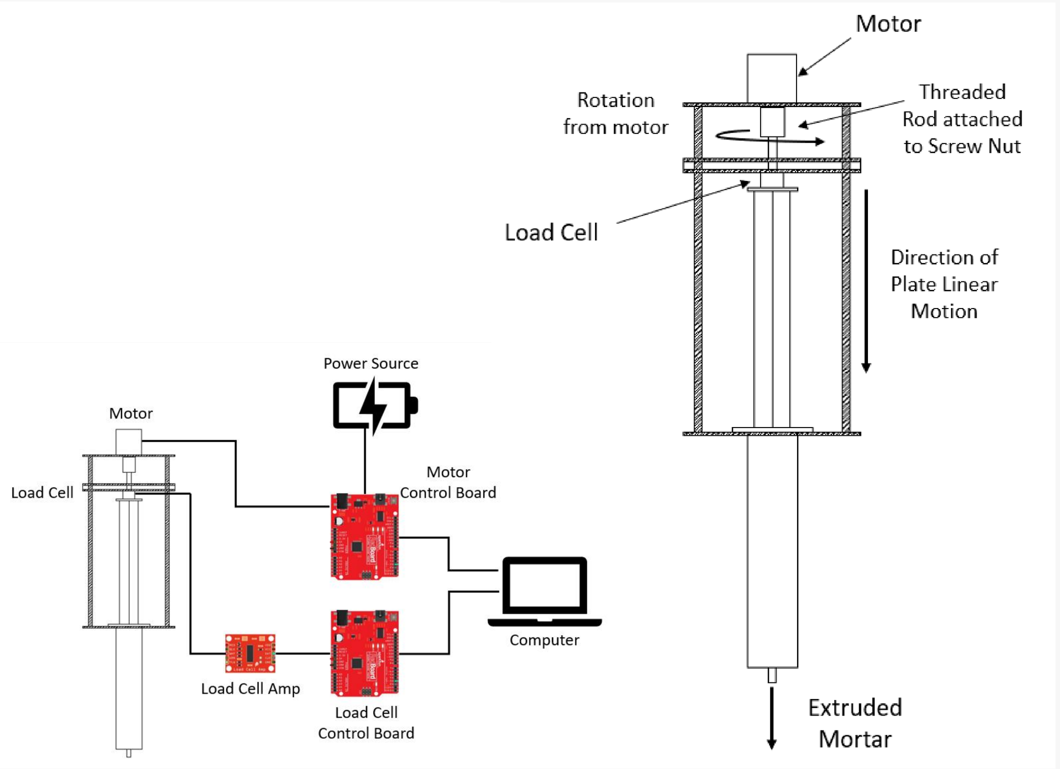
Objectives

- Develop test methods to characterize extrusion in 3D printing cement-based materials
- Design modular head extruder for 3D printer with test measurement capabilities
- Investigate effect of nozzle size, particle size, rheology, and extrusion speed on extrudability
- Compare flexural properties of manually printed beams versus cast beams

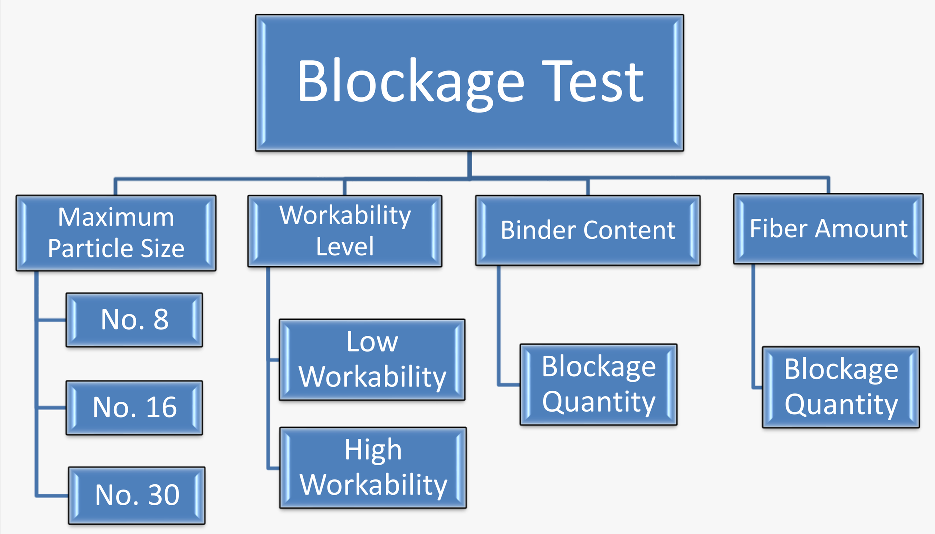
Extruder Design

Features:

- Displacement Controlled
- Measures Extrusion Force
- Capable to Add to Future 3D Printer



Test Methods



Extrudability:

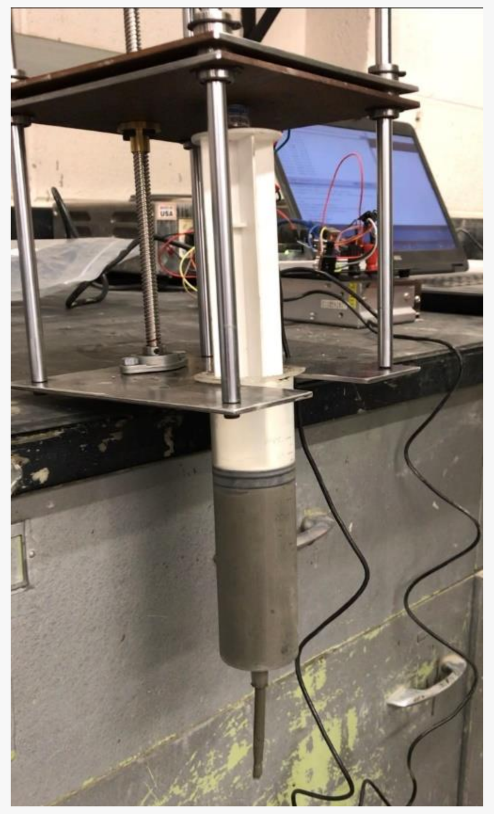
- Blockage Test
- Mini-Slump
- Rheology on ConTec 6
- Ram Extrusion Test for Printing

Flexure:

- 3 Point Bending
- Fiber Orientation Analysis

ConTec 6 Rheometer

3 Point-Bending on Manually Printed Beam



Ram Extrusion Test

Results

Blockage

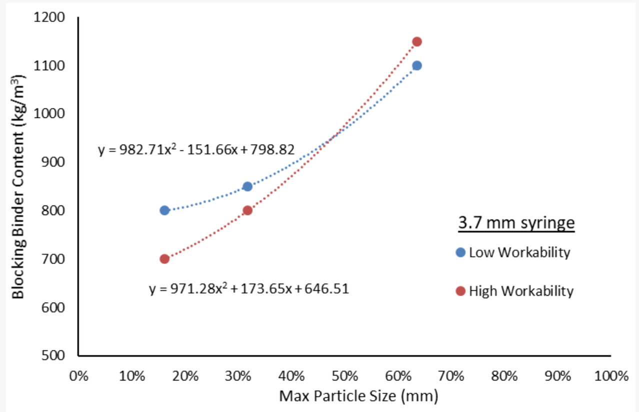


Figure 1: Blocking Binder Content vs. Particle Size % of Nozzle Diameter

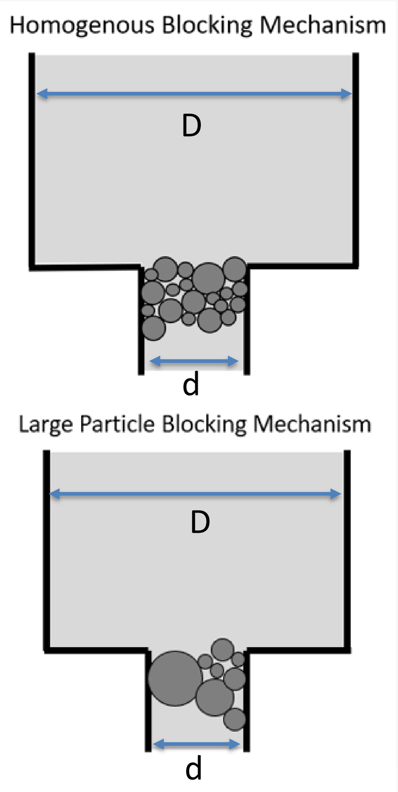


Figure 2: Extrusion Blocking Mechanisms

Ram Extrusion

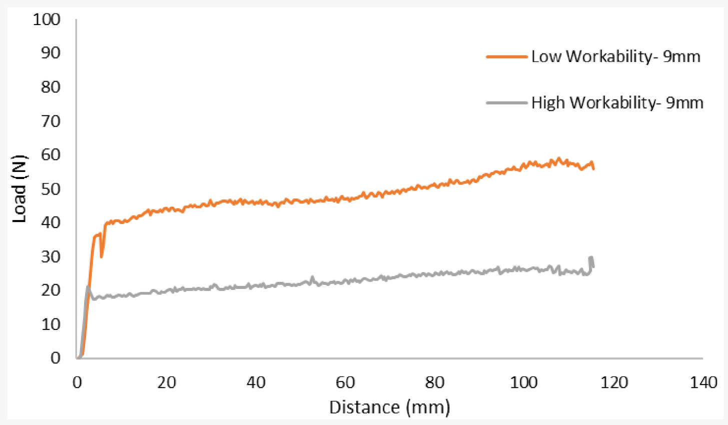


Figure 3: Extrusion force vs. Displacement

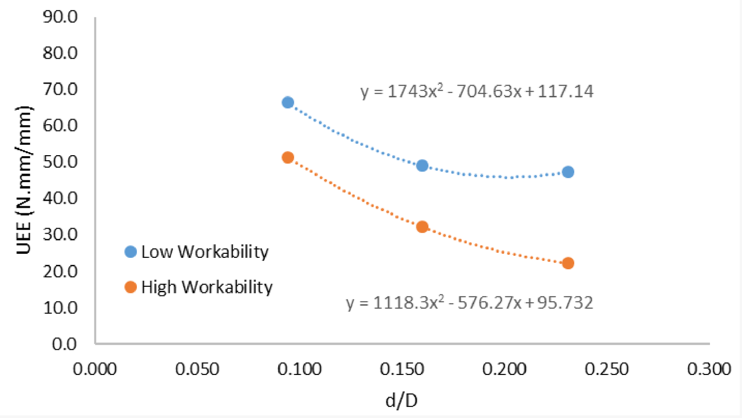


Figure 4: Unit Extrusion Energy versus Nozzle Ratio

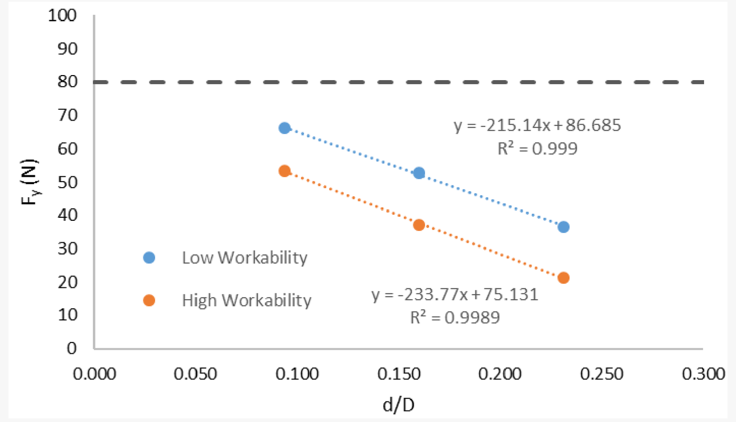


Figure 5: Initial Extrusion Force vs. Nozzle Ratio

Flexural Comparison

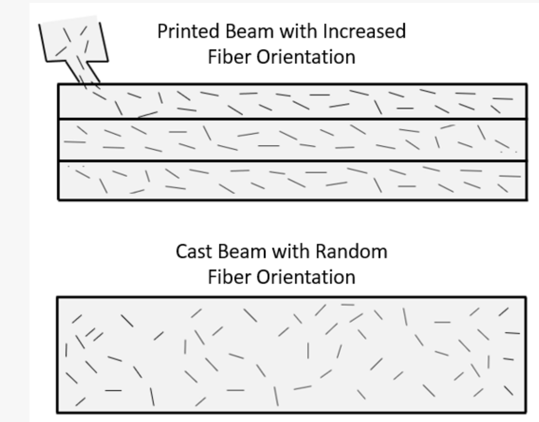


Figure 6: Effect of Printing on Fiber Orientation

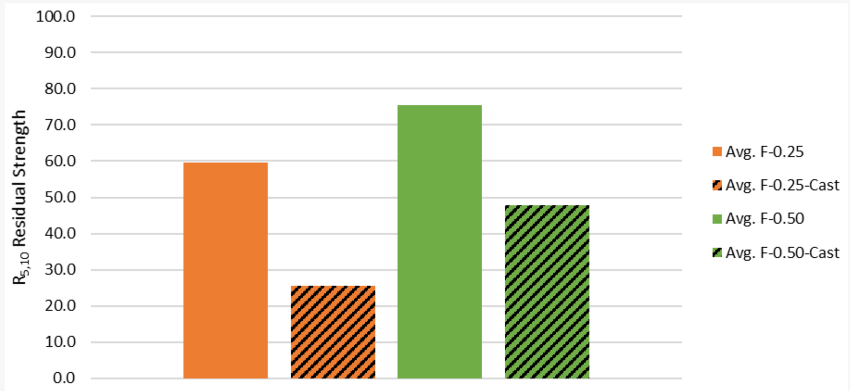


Figure 7: Residual Strength – Cast vs. Printed

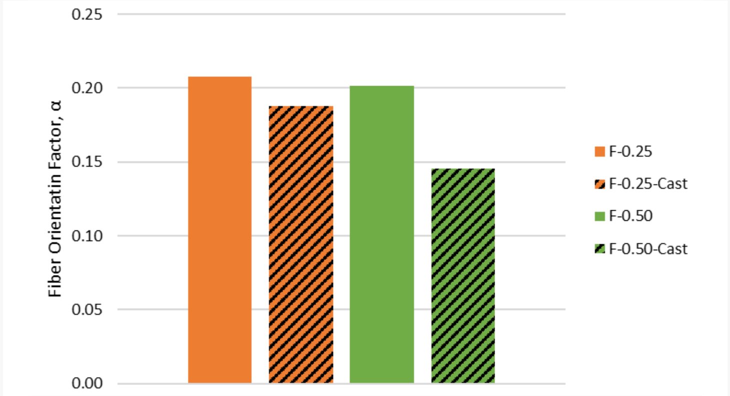


Figure 8: Fiber Orientation Factor – Cast vs. Printed

Conclusions

- The Blockage Test was found useful for developing mix designs to prevent blocking by defining a maximum binder content that still causes blocking for a particle size
- Test methods were successfully developed to help define blocking during extrusion, extrusion force and energy needed for a system, and evaluate effects of rheology, nozzle size, and extrusion speed
- The effect of different extrusion parameters were evaluated: yield stress increases extrusion force and energy for all nozzle sizes, increasing the nozzle diameter compared to extruder diameter decreases extrusion force and energy, and increasing extrusion rate increases force and energy
- The printed specimens had a lower first-crack stress. The residual strength, toughness, and fiber orientation all improved from printing however.

Impact:

This work helps characterize the first step in the process of 3D printing concrete which has not been well studied in other research. Understanding extrusion will help improve mix design and develop printing systems better. Also, finding the improved post-crack properties from printing verifies fibers as a beneficial reinforcement, especially compared to cast fiber-reinforced concrete.

Future Work:

Future work will include adding the extruder to a 1m x 1m printer, studying the effects of packing density on extrusion, and developing a workability box for extruding concrete for printing.

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