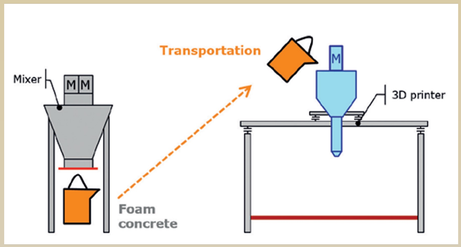
Development of an Ultra-High Strength 3D Printable Blast Resistance Concrete

Brendan Crotty, Avery Lyons, and Dr. Phillip Mulligan
Funded By: Devcom Analysis Center – Ft. Leonard Wood
Department of Mechanical and Aerospace Engineering

Introduction

- This study focuses on the development of an ultra-high performance and blast resistant concrete that also possesses optimal characteristics for 3D printing such as extrudability, flowability, slump, surface tension, dry time, and cost.



Concrete 3D Printing Work-Flow Diagram

- Throughout our research we found that although concrete 3D printing has become very popular in construction and housing applications, very little research in printing with aggregate, steel/polymer fibers, or chemical additives, nonetheless all three, has taken place.

- The design was based off an ultra-high strength performance concrete (UHPC) that was heavily modified to alter the printing characteristics including:
  - Medium sized aggregate
  - Physical additives such as steep and/or polymer fibers
  - Chemical additives such as a superplasticizer or viscosity modifying admixture (VMA)

- The difficulty of this design was finding a blend that balanced overall compressive and tensile strength while also being printable.

3D Printed House Constructed in Germany

Ballistic Testing on Concrete Samples

Approach

Commercial Design (Baseline)

- The commercial design was based on a UHPC blend and compared fiber content relative to compression strength as a dispersed rebar replacement.
- Multiple batches were tested at a 3,7-, and 15-day dry time with samples of 20 through 80 lbs./yd of steel fibers.
- The increase in fiber content directly correlated to compressive strength until a certain point where we started to observe an inverse affect.

Fresh poured UHPC cylinders

UHPC Cylinder After Compression Testing. Compressive testing hit over 8000 psi

Printable Mortar Design (Traditional Mortar Mix)

3D Printed Mortar Example

- The printable mortar design was used to characterize our 3D printer with a conventional 3D print mix design
- The mortar design allowed us to compare water content and fluidity with extrudability and print settings.

Printable UHPC Design

- The printable UHPC Design was made taking into account the results from the commercial design for fiber content
- The final mix design includes 1" steel fibers, a medium-sized crushed aggregate, and several chemical additives
- The mix design has little to no slump, good layer printing adhesion, and has a long working life

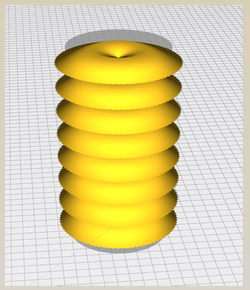
Printable UHPC Wall Structure

3D Printed Concrete Pickaxe

Results

Results:

- The commercial design results show that fiber levels above 20lb/yd inversely affect compressive strength, however are still stronger than the control group with no steel fibers.
- The next phase of testing will consist of 3D printing the same standard cylinders using the printable UHPC design mix.
- This will allow us to compare a commercially poured UHPC mix design with the 3D printed UHPC design in terms of compression strength
- We will also be conducting shear tests with the 3D printed cylinders to observe layer adhesion strength



3D Printed Cylinder For Compression Testing

Poured compression test cylinder

Printed UHPC wall structure

Acknowledgements

We would like to acknowledge Jeff Heniff, Jason Cox, Greg Leckrone, Jacob Sneed, Anton Lessmeister, Garrett Weiner, Eric Bonney, and Cade Hilger who have helped make this project possible.

References

[1] Viacheslav Markin, Viktor Mechtcherine, TU Dresde, 3D Printing with Foam Concrete, , 2016
[2] Garrett Weiner, Gunnar Wurst, Tony Lessmeister, Taghi Sherizadeh, Phillip Mulligan, Triangulating Impact Location in 3D Printable Concrete Using Fiber Bragg Grating Sensors, 2022
[3] Madeleine P., What Do We Know About the First 3D-Printed House Inaugurated in Germany?, August 2021
[4] The Portland Cement Association, Ultra-High Performance Concrete, 2023