Lessons from a Failed 3DCP Project: Could Standards Have Helped?

ICC 1150 3DCP Standard Development

Bing Tian, Ph.D.
Abdul Peerzada, Ph.D.
Austin Sanderson

The Quikrete Companies

ACI 2024 –New Orleans

3DCP - Great Excitement…*but, it's the Wild West out there*

A new neighborhood in Muscatine will be home to 3D-printed houses thanks to an Iowa City-based company

Paris Barraza
Iowa City Press-Citizen
Published 12:30 p.m. CT May 19, 2023

EDITORS' PICK

Iowa Teardown Exposes Problems Of 3-D-Printing Homes

- Faster construction
- Low Cost
- Low waste
- Resilient

- No material standards
- No building code
- No jobsite testing procedure
- Trial and error on jobsite

Pre-blended 3DCP Printing Mortar

- Multiple suppliers
- Pre-packaged in a factory
- Engineered to specific properties for printability and constructability
- Quality-controlled, warrantied and technically serviced

3DCP Residence
in Richmond VA in -2021

3DCP Live Demo at WOC-2024

The first 3D Printed
2 Story House in USA-2023

COMMERCIAL GRADE QUIKRETE

3D PRINTING MIX

PRODUCT NO. SR210013D

DIVISION 3

03 37 00 Specialty Placed Concrete

PRODUCT DESCRIPTION

QUIKRETE® Commercial Grade 3D Printing Mix is a high-strength, low slump, pump-able, rapid hardening, pre-blended mortar designed for 3D printing applications, requiring only the addition of water.

PRODUCT USE

QUIKRETE® 3D Printing Mix is a fast-setting, high early strength mortar designed for use with large scale 3D Printers. QUIKRETE® 3D Printing Mix exhibits less shrinkage than ordinary Portland cement mortar. The QUIKRETE® 3D Printing Mix is optimized for pump-ability, printability, buildability and allows for maximum open time for superior workability. QUIKRETE® 3D Printing Mix is also available in a coarse concrete version.

SIZES

- 3000 lb (1360.7 kg) super sack

YIELD

- One 3000 lb (1360.7 kg) super sack will yield approximately 1 yd³ (0.76 m³)

TECHNICAL DATA

APPLICABLE STANDARDS

- ASTM C109 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2 in. or [50-mm] Cube Specimens)
- ASTM C157 Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete
- ASTM C1437 Standard Test Method for Flow of Hydraulic Cement Mortar
- ASTM C191 Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle
- ACI 305R Guide to Hot Weather Concreting
- ACI 306R Guide to Cold Weather Concreting

PHYSICAL/CHEMICAL

Typical results obtained for QUIKRETE® 3D Printing Mix, when tested in accordance with the referenced ASTM test methods, are shown in Table 1.

INSTALLATION

SURFACE PREPARATION

The substrate should be clean and free of foreign substances. The substrate should also be level and able to support the total printed structure design weight. The appropriate personal protective equipment should be worn. For application over existing hardened 3D printed layer, prime the clean dry surface with diluted QUIKRETE® Concrete Bonding Adhesive (No. 9902). The primer should consist of 1 part QUIKRETE® Concrete Bonding Adhesive (No. 9902) blended with 2 parts water to obtain the proper penetration into the sublayer. Excessively porous concrete may require 2 coats.

MIXING

Mechanically mix QUIKRETE® 3D Printing Mix for 3 to 4 minutes using a paddle type mortar mixer. Use approximately 3-1/4 quarts (3.1 L) of clean potable water per 50 lb (22.6 kg) of QUIKRETE® 3D Printing Mix. Adjust water, if needed, to achieve a place-able consistency. If more water is needed, add small amounts at a time and continue to mix until desired consistency is achieved. Exceeding an ASTM C1437 flow of 120% is not recommended. This may cause sagging and a reduction in performance of the product.

APPLICATION

Print the QUIKRETE® 3D Printing Mix following the direction provided by the printing system. The buildability of the materials will vary according to the water dosage. The set time and early strength development of the QUIKRETE® 3D Printing Mix is also temperature depended. Applying the concrete below 50 °F (10 °C) will slow down the set time hence affect buildability and early compressive strength.

CURING

The fresh mix of QUIKRETE® 3D Printing Mix should be protected against drafts and excessive heat to premature drying out. Moist curing should begin as soon as product is hardened enough to not be damaged by a gentle mist of water. Continue moist curing for 24 to 48 hours prior to use. When covering, use wet burlap or plastic sheet to prevent from rapid drying.

PRECAUTIONS

- Mix no more than can be used in 30 minutes.
- Follow ACI 305R when using product in hot weather. An example of an additional step would be using cold water when mixing in extremely hot weather.

1st Trial:
Local mix + Commercial 3D additive

Didn't Work

2nd Trial:
Quikrete 3D Printing Mix

Teardown

3rd Trial:
Geopolymer

Didn't Work

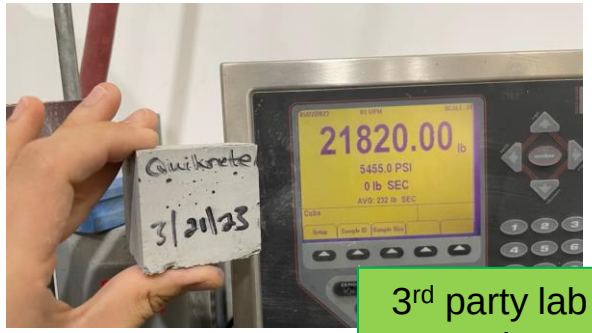
- What are the minimum qualification for 3DCP materials?
- Who makes selection of 3DCP materials based on performance & cost?
- How to properly inspect the field performance and quality?

Why was the 3DCP House Torn Down?

- Structure engineer specified >5000 psi @ 28d
- The Quikrete 3D Printing Mix was tested at a 3rd party independent lab, meeting TDS and job spec > 5000 psi.
- The local field-testing lab indicated the 28 days strength was <5000 psi (~3500-5000 psi).
- The owners and designers decided to demolish the finished walls and closed the project.

TABLE 1 TYPICAL PHYSICAL PROPERTIES

Flow, ASTM C1437	
At 5 minutes	105% to 120%
Compressive Strength, ASTM C109	
Age	*PSI (MPa)*
1 Day	2000 (13.7)
7 days	4000 (27.5)
28 days	5000 (34.4)
Setting Time, ASTM C191	
Final	110 to 160 minutes
Length Change, ASTM C157	
Age, Condition	
28 days, air	≥ -0.10%



3rd party lab testing result 5455 psi

- What strength is needed?
- How should that strength be measured on site?
- What is the impact of printing on strength?
- Reinforcing requirements?

3DCP Standards, Specifications & Codes Under Development

- **ICC AC509** *3D Automated Construction Technology for 3d Concrete Walls – 2021*
- **IS-3DACT** *3D Automated Construction Technology for 3D Concrete Walls Consensus Committee* are formed in 2023
- **ICC 1150** *Standard for 3D Automated Construction Technology for 3D Concrete Walls* – ongoing

- **Innovation Task Group 93-12 ITG-12 (ITG-12)** to develop code requirements, design, and prescriptive provisions for additively constructed above-grade concrete walls for residential structures for incorporation into ACI 332 and IRC. **Request for Proposal** from qualified firms to create design and prescriptive code provisions.
- **ACI Committee 564** - **3-D Printing with Cementitious Materials**
  - 564-0A Emerging Technology Report
  - 564-0B Structural Design and Testing
  - 564-0C Material Testing and Formulation
  - 564-0D Modeling and Performance Prediction

- **ISO / ASTM 52939:2023-11** *Additive manufacturing for construction — Qualification principles — Structural and infrastructure elements*
- ***ISO JG80*** and ***ASTM F42.07.07 Subcommittee -*** *Construction*

IS-3DACT Material Group Activities

3DCP Material Prequalification

Existing ASTM methods are used

- Workability
- Air content
- f/t
- Compressive strength & MOE
- Shrinkage

3DCP Field QC and QA

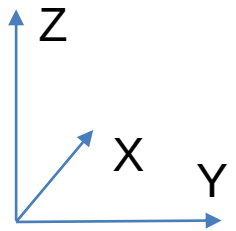
Freshly Mixed Materials

- Sampling from printer nozzle!!!
- Workability (slump)
- Air content

Hardened Materials – Cut out Specimen from Mockup Wall

- Compressive strength
- Interlayer bond strength

A mockup wall is needed for cutting out specimen for QC



anisotropic in x, y or z direction

Summary

- **Standards can help avoiding costly (and potentially dangerous) mistakes that hurt the adoption of a promising technology**
- **Any standards should not limit innovation**
- **Don’t underestimate 3DCP --** it may *not* be cheap, fast, cost efficient, sustainable, etc., **yet**, it has many benefits, such as automated construction, design flexibility (shape, contour and aesthetics), durability, and hazard resistance (fire, hurricane, tornado, pest etc.).
- **Working out high quality, unbiased, and efficient standards, specifications & codes is not an easy task**. Volunteers, please join us.

Thanks! Questions?

Bing Tian, Ph.D.
bing.tian@quikrete.com