Rapidly Deployable System for the Structural Stabilization of Shock Damaged Structures

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Project Sponsored through:

National Institute for Hometown Security

Collaborative Partners

- **Minova USA**

- **University of Dundee & University of Aberdeen**

Project Objectives

- **Purpose of project and project outcome**
  - A system deployable with first responders capable of stabilizing blast damaged structures.
    - A new formulation for a shotcrete material
    - Rapid deployment system that utilizes new shotcrete materials
    - Single bag mix with good stability and a reasonable shelf life
    - Advanced Technology Level 7

- **Homeland security critical infrastructure protection** – ***DHS Need***
  - 2003 Homeland Security Directive 7 "Development of rapidly deployable automated response and fast recovery technologies"

- **Securing the Nation**
  - This work serves the mandate in NIPP for international collaboration. In particular with the coordinated research efforts with our colleagues in the United Kingdom to improve our protective capabilities.

Project Tasks

- **Phase 1: Development of CSA Based Shotcrete**
  - Fabrication of Cements
    - rapid hardening; high in ultimate strength; excellent bonding
  - Shotcrete Formulation and Materials Testing
    - CSA shotcrete mixes, fiber testing, shotcrete/substrate bond testing, shelf life of material
  - Bonding of Shotcrete to a Damaged Surface
    - Interaction between shotcrete and damaged surface is very complex and important
  - Fiber-Reinforcement of Shotcrete
    - Shotcrete is a brittle material
    - Fibers provide ductility to the material, as well as energy absorption capacity, and impact resistance
- **Phase 2: Integration of Materials and Delivery Systems**
  - Selection of Transport Systems
    - Evaluation of wet and dry systems
  - Design Configuration of Final Prototype System
  - Evaluation of Final Materials and Prototype System
    - Field testing of prototype system, Testing of field emplaced materials, operational protocols, final prototype system design

Rapid Hardening Cement

- **Rapid hardening cements**
  - Portland cements currently used for bulk of rapid repair
  - Three types of CSA cements will be studied:
    - Calcium sulfate hemihydrate – “Plaster” Cements
    - Calcium sulfoferroaluminate (CSFA)
    - Calcium sulfoaluminate (CSA)
  - CSA can be made from industrial waste and coal combustion by-products
    - Ettringite – cementitious phase responsible for high early strengths

CSA/B and OPC cement reactions

CSA: Ettringite Formation

$Ca_4Al_6O_{12}SO_4 + 2\ CaSO_4 + 38\ H_2O \rightarrow Ca_6Al_2(SO_4)_3(OH)_{12}\bullet 26\ H_2O + 4Al(OH)_3$

Klines Compound + Gypsum/Anhydrite → Ettringite + Aluminum Hydroxide

Portland: Hydration of Tricalcium Silicate

$2[3CaO\bullet SiO_2] + 7H_2O \rightarrow 3CaO\bullet 2SiO_2\bullet 4H_2O + 3Ca(OH)_2$

Alite → C-S-H Gel + Portlandite

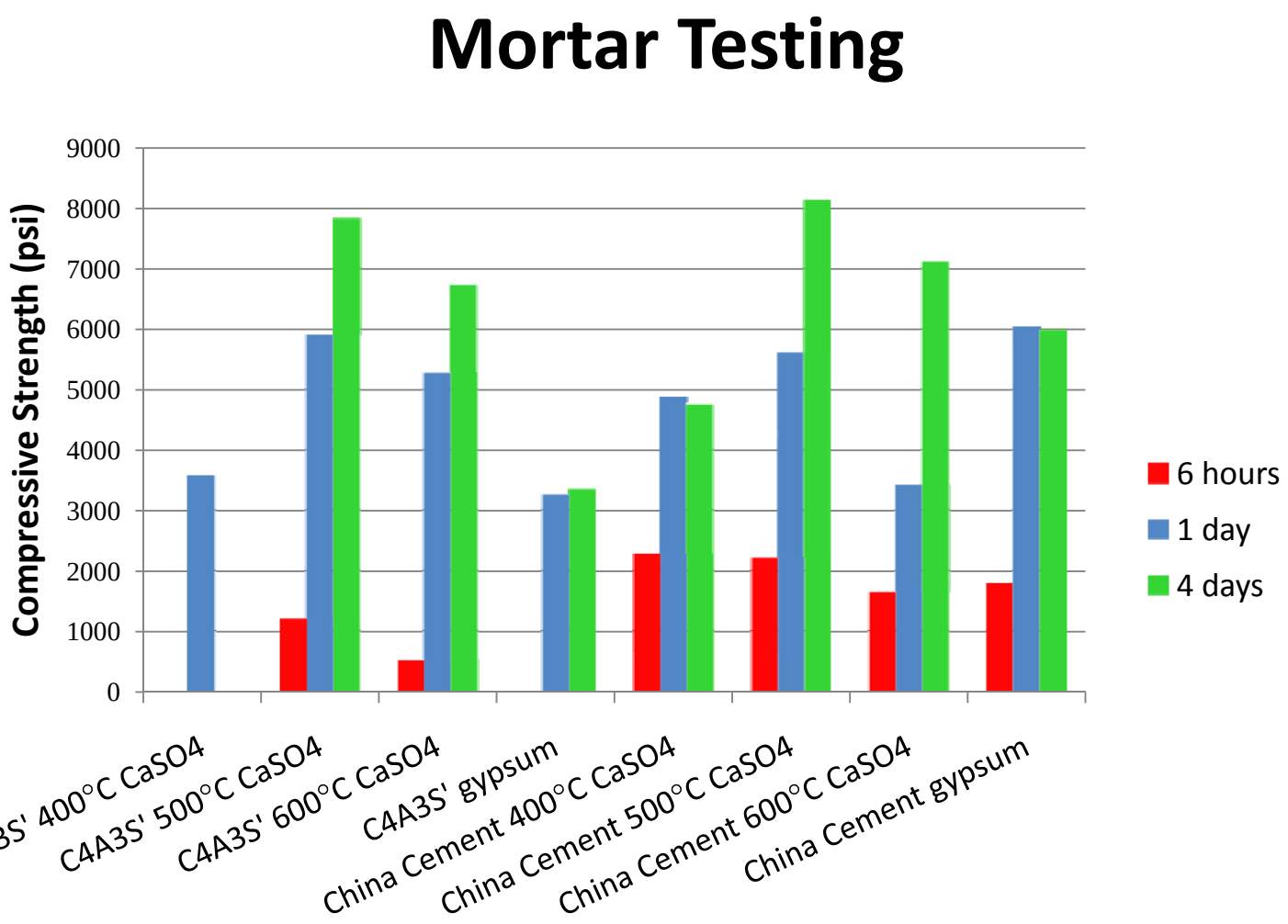
Both

Hydration of Dicalcium Silicate

$2[2CaO\bullet SiO_2] + 5H_2O \rightarrow 3CaO\bullet 2SiO_2\bullet 4H_2O + Ca(OH)_2$

Belite → C-S-H Gel + Portlandite

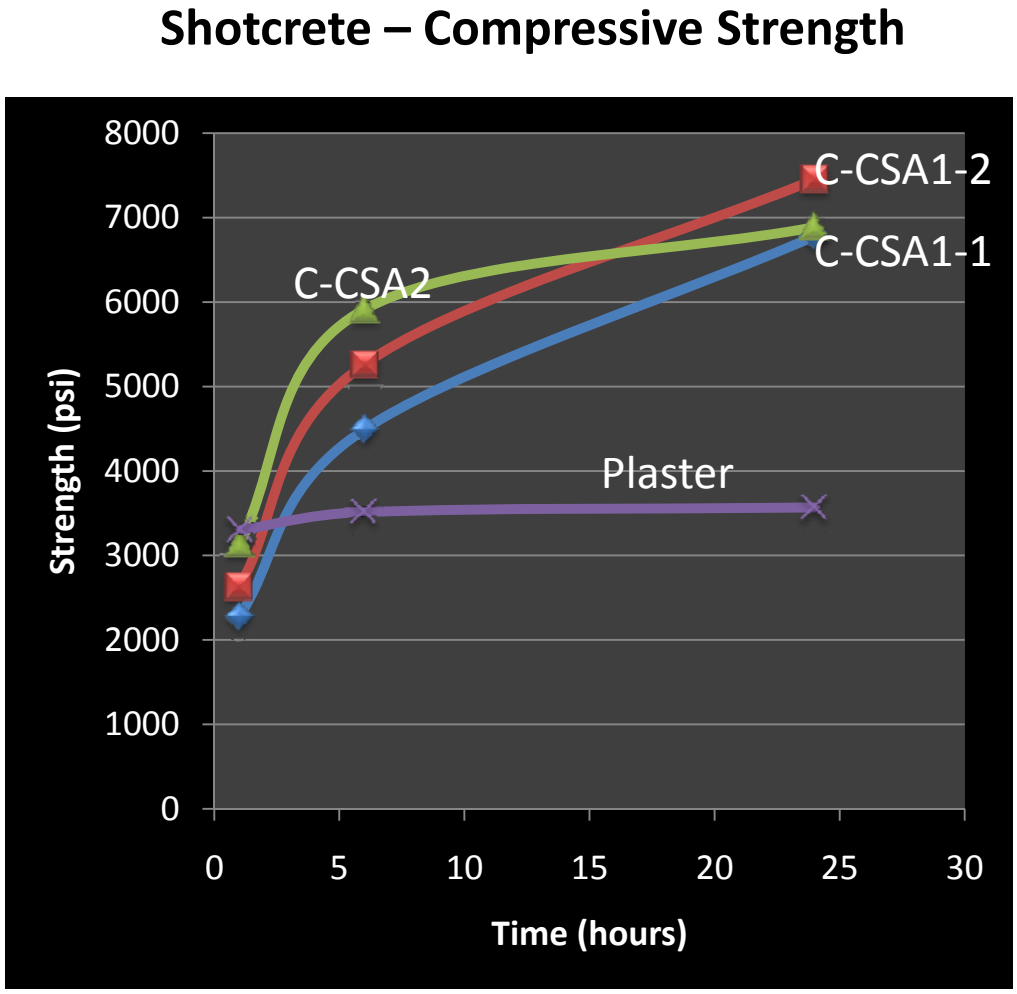
Sulfate Optimization



CSA-Strength Development

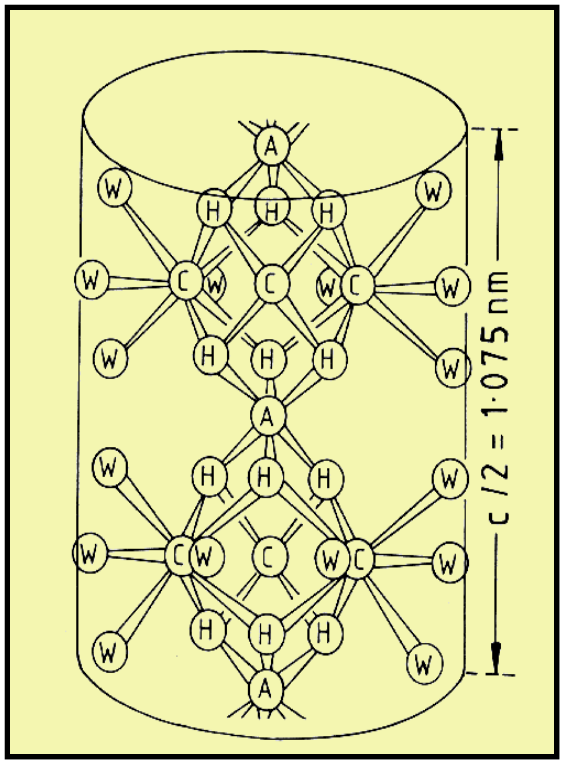
Component (g)	C-CSA1 Mix#1	C-CSA1 Mix#2
Cement	494	500
Sand	1460	1470
Water	244	222
w:c	0.45	0.40
s:c	3	3

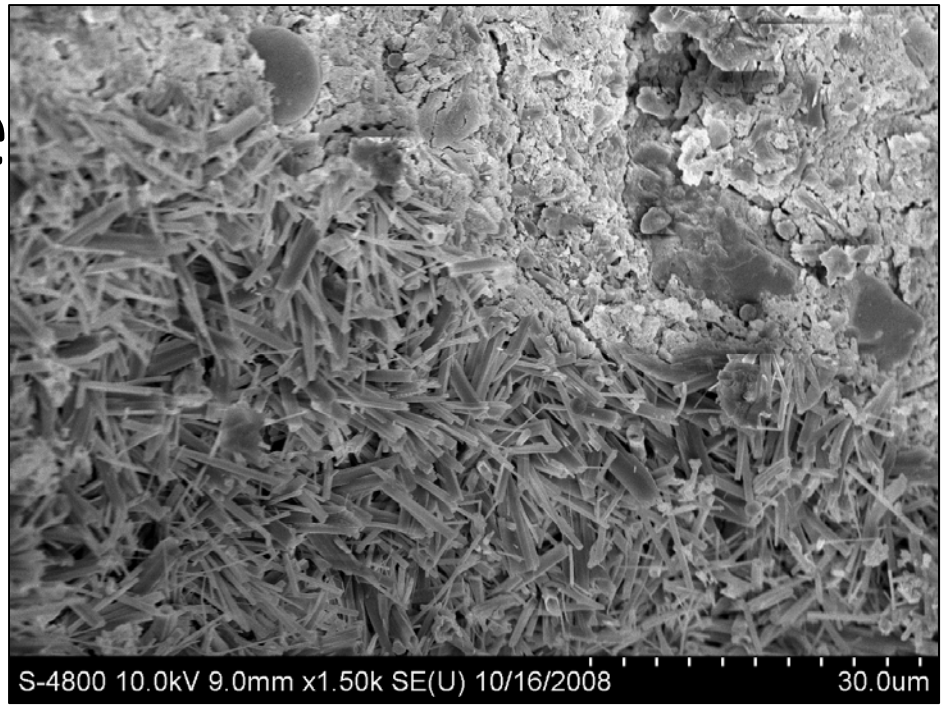
Component (g)	C-CSA2	Plaster
Cement	719	362.5
Sand	2110	740
Water	320	120
w:c	0.40	0.30
s:c	3	2

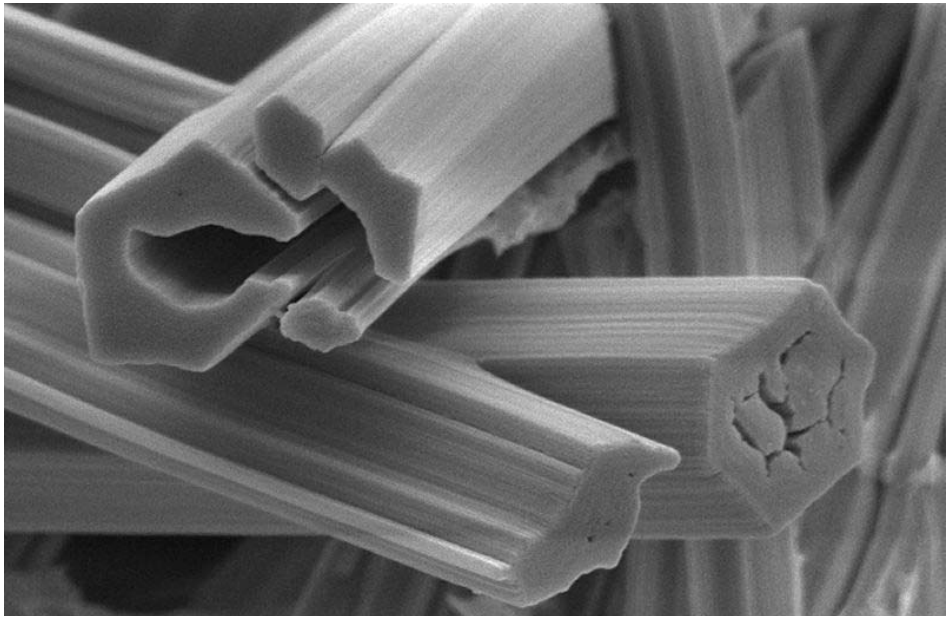


CSA is an Ettringite Forming Cement

Ettringite Structure





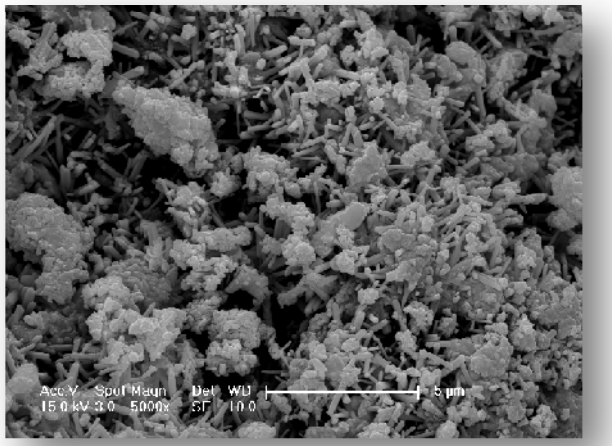


Set Time Testing

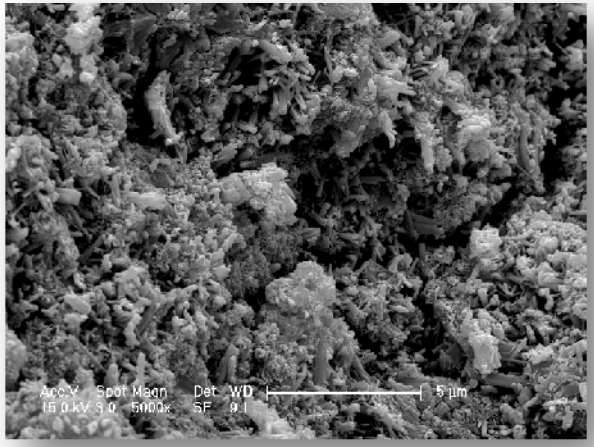
- Shotcrete – Time of Set

Cement	Set Time (minutes)
Ordinary Portland Cement	222
C-CSA #2	14
C-CSA#1, wet-mix, no admix	**5.5**
C-CSA#1, (dry-mix) no admix	**4.5**
C-CSA#1 (wet-mix) w/ 2.03mL Grace Recover	**16**
Import HS (high strength)	178
Import HS w/35% gypsum	84
Import HS w/35% Anhydrite	12
Plaster	12

C-CSA#1 after 1-day of curing



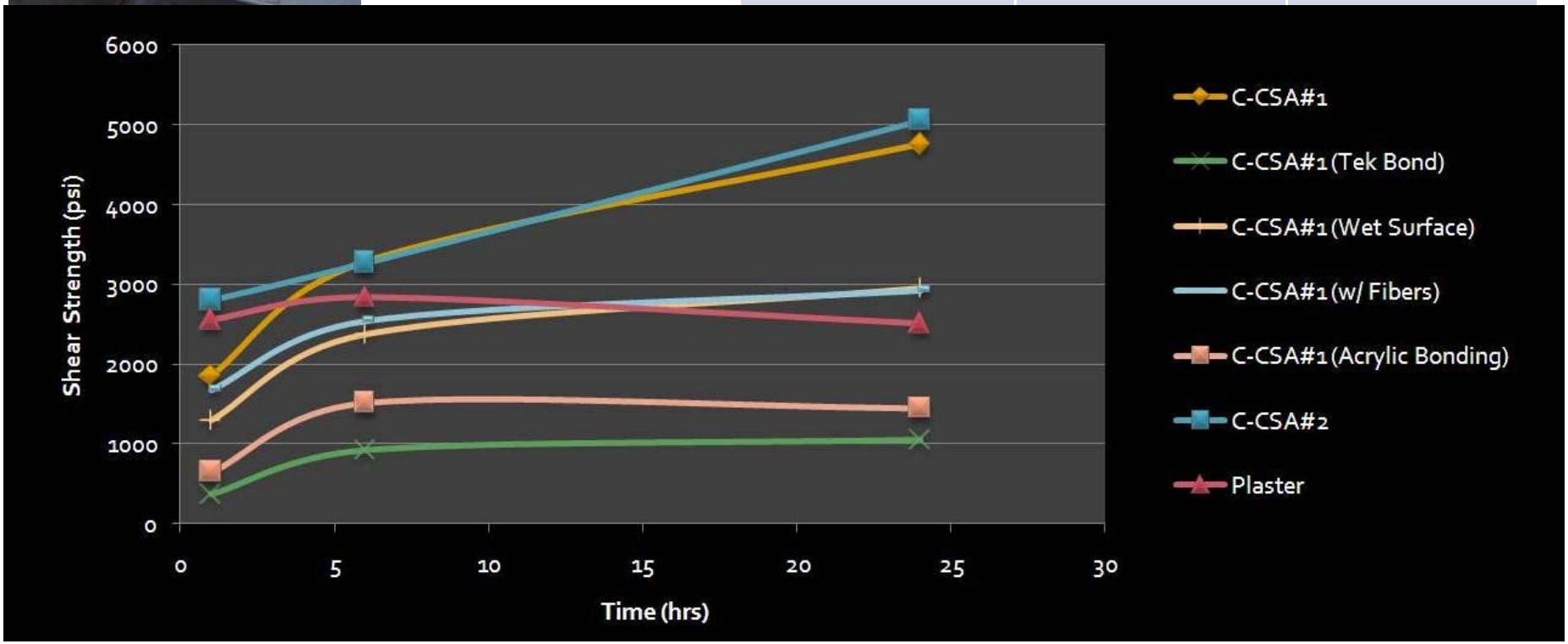
C-CSA#2 after 1-day of curing



Bonding Testing: Slant Shear

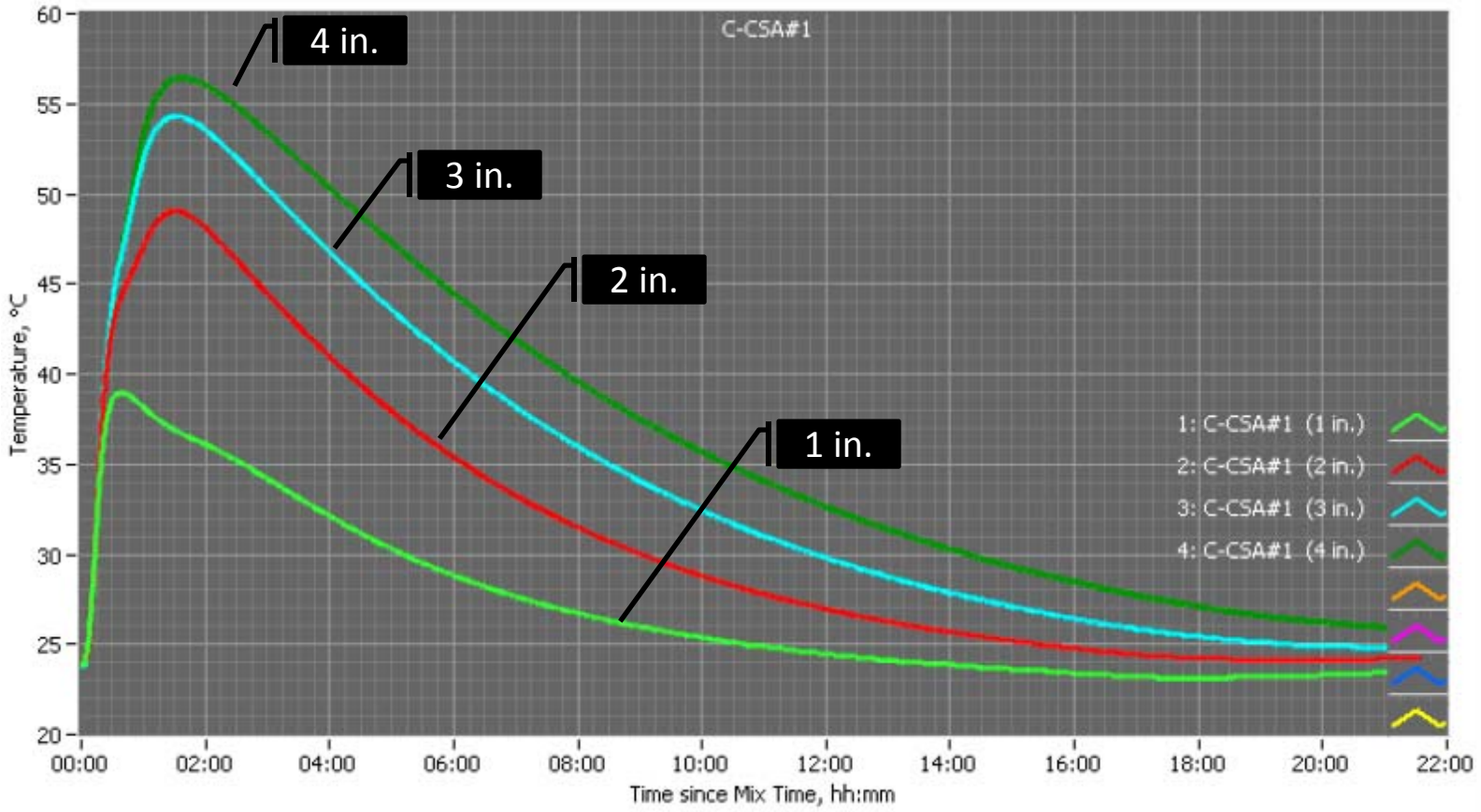
- Ability to bond fresh shotcrete to hardened concrete

Component (g)	C-CSA1	C-CSA2
Cement	510	511
Sand	1536	1534
Water	204	204.4
Admixture (mL)	690	280
w:c	0.40	0.40



Thermal Testing: Heat Rise

- Adiabatic Calorimetry – *Effect of layering on heat gain*
  - Shotcrete thicknesses tested: 1, 2, 3, and 4 inches
    - C-CSA1 mix#2 *(shown below)*



Materials Delivery System

- System must be self contained, robust, and capable of operating in a stressed environment
  - Designed to quickly remedy problems
  - Simple operability
- Proper equipment selection
  - Work with rapid set times of the cement
  - Handle viscous materials

Gunnite Machine
(www.reedpumps.com)

System Delivery Dry/Wet

Gunite training and test work 11/5/09-11/6/09

Rebuilt Reed SOVA Gunite Machine

Initial Gunite Testing

Gunite training and test work

Buzzi CSA mortar
29% Cement

Minova Techcrete Control

First Test of CSA proved successful
Good results
Simple operability

Conclusions to Date

- CSA cements
  - Can be formulated for both rapid set and rapid strength gain
  - Can achieve very high ultimate strength
    - >90 MPa (>13,000 psi) in 72 hours
  - Heat gain can be managed within critical limits
    - <60 °C
  - Show unusually good bonding characteristics
  - Show promising long term stability
  - Can be formulated in a single bag mix
  - May be best delivered by dry-wet systems (gunite)

Thanks!

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