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http://www.flyash.info/

THERMAL PERFORMANCE OF HIGH VOLUME FLY ASH CONCRETE

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  - Dr. Ross Corotis
  - Dr. Yunping Xi

Thermal Analysis and Calorimetry

Significance

- Universal methods
- Yields useful information (especially for mixtures)
- Exposes information not visible or obvious to the analyst
  - Molecular structure
  - Bonding
- Physical or chemical changes

Methods

$$Q = \sum m_i c_{pi} \Delta t_i$$

$$Q = \text{heat of reaction}$$

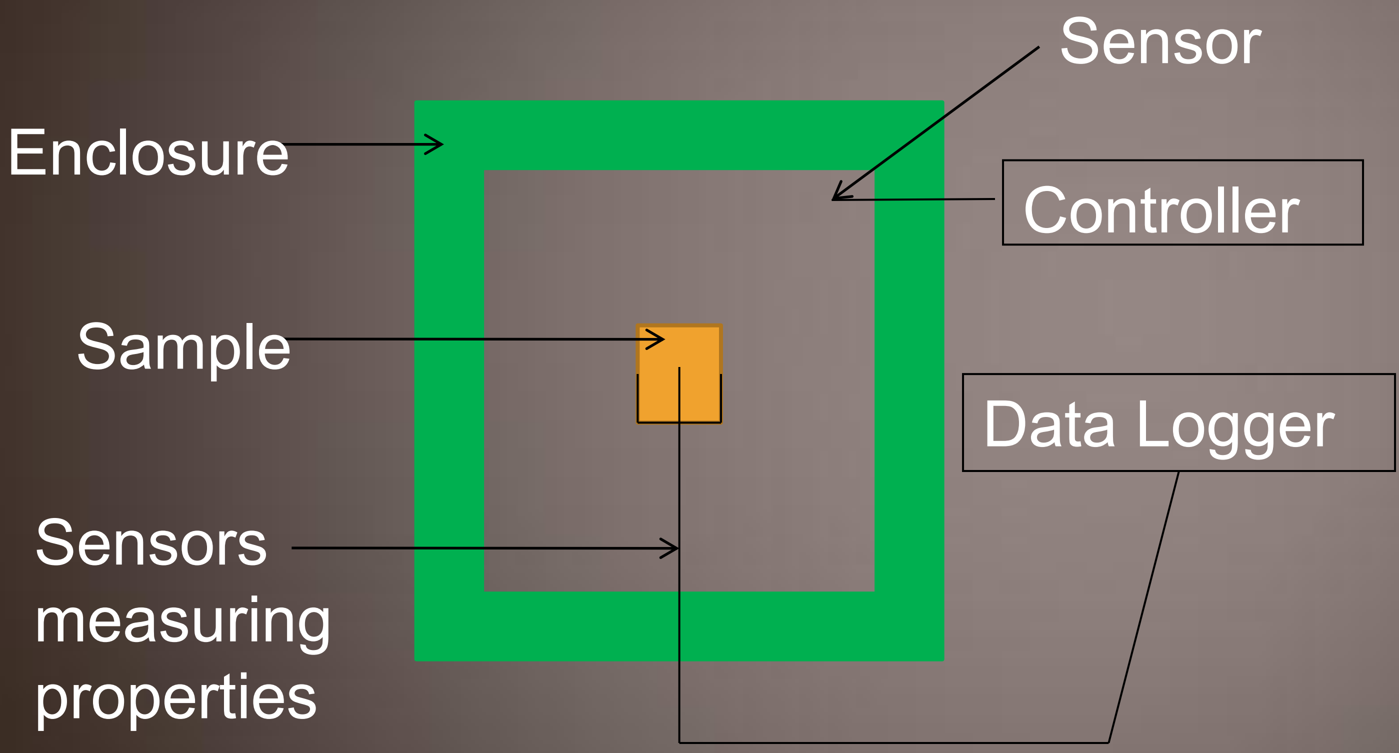
$$\text{m} = \text{mass of sample}$$

$$\Delta\text{t} = \text{temperature change}$$

$$\text{c} = \text{specific heat capacity}$$

- Calorimetry
  - Measuring heat changes during a process
  - Measurement under constant volume, constant pressure, constant temperature
- Thermal Methods
  - Measuring properties such as mass, temperature difference, sound, deformations
  - Measurement under constant heat rate, isothermally, cyclic heating, stepwise heating, heating controlled by sample

General Apparatus



Technique
Thermo-gravimetry
Differential Scanning Cal.
Thermo-mechanical
Differential Thermal

Source: Heal , G. R. et. al (2002)

Attaining good, reproducible results

- Sample description
- Container choice
- Rate of heating
- Nature of atmosphere
- Mass of sample

Thermal Analysis of Fly Ash Concrete

History of analysis

- Heat of hydration or heat evolution
  - Davis et al., 1937 established many properties including low heat of hydration
  - Ravina, D. 1970 associating benefits with hot weather concreting
  - Maholtra, V. M. 1980s motivated research on high volume fly ash, mass concrete, internal heat
  - Bentz, D. P. et al., 2011 associated fly ash with energy efficiency

Literature

Author	Published Year	Percentage of fly ash used
Ravina, D.	1981	0%, 20%, 30%
Mehta, P. K.	2002	57%
Senthil, S. & Santhakumar, A. R.	2005	0% and Blended cement (unknown %)
Bentz, D. P., Peltz, M. A., Durán-Herrera A., Valdez, P., Juárez, C. A.	2010	0%, 15%, 30%, 45%, 60%, 75%

Literature

Author	Relative Humidity	Lab or Field Curing Temperature	Additional Testing Variables
Ravina, D.	65% or water cured	20°C (68°F), 40°C (104°F)	Phase I - water content kept constant, Phase II - slump kept constant
Mehta, P. K.	80%-100%	25°C (77°F) to 30°C (86°F)	Maintaining a rise in internal curing temperature between 15°C (27°F)-30°C (54°F) for massive concrete structural members in order to prevent thermal cracking
Senthil, S. & Santhakumar, A. R.	unknown (testing occurred in humidity controlled chamber), water curing and a water curing compound were also used	unknown	Measure the variation of temperature over time, strength with different curing and heat dissipation methods, and temperature at different depths of a sample with a 1 m height 3.28 ft
Bentz, D. P., Peltz, M. A., Durán-Herrera A., Valdez, P., Juárez, C. A.	some cured in a lime solution and others in sealed plastic conditions in 40% humidity	25°C (77°F)	Measure specific heat capacity, thermal conductivity (transient plane method) of mortars and concretes

Literature

Author	Summary of Results
Ravina, D.	slump decrease smaller in FA, elevated temperature causes increase in mixing water to maintain slump, compressive strength in FA not affected by elevated temperature
Mehta, P. K.	50% or more cement replacement by FA can proved cost effect and durable structures in warm climates. Internal temp. rise is lower than OPC, heat of hyrdation accelerates pozzolanic reaction instead of thermal cracking from temperature rise.
Senthil, S. & Santhakumar, A. R.	The heat of hydration higher for blended cement than for Grade 43 cement concrete [55°C (131°F) vs. 50°C (122°F)]. Compressive strength of blended cement was 47 MPa vs. 49 MPa for the Grade 43 cement
Bentz, D. P., Peltz, M. A., Durán-Herrera A., Valdez, P., Juárez, C. A.	Specific heat capacities - No significant difference between OPC and FA samples. FA reduced thermal conductivity up to 19% compared to OPC samples. Reduced densities also meant reduced thermal conductivities due to light weight aggregate used. Reduction in heat and cooling costs can result from low thermal conductivity

Literature

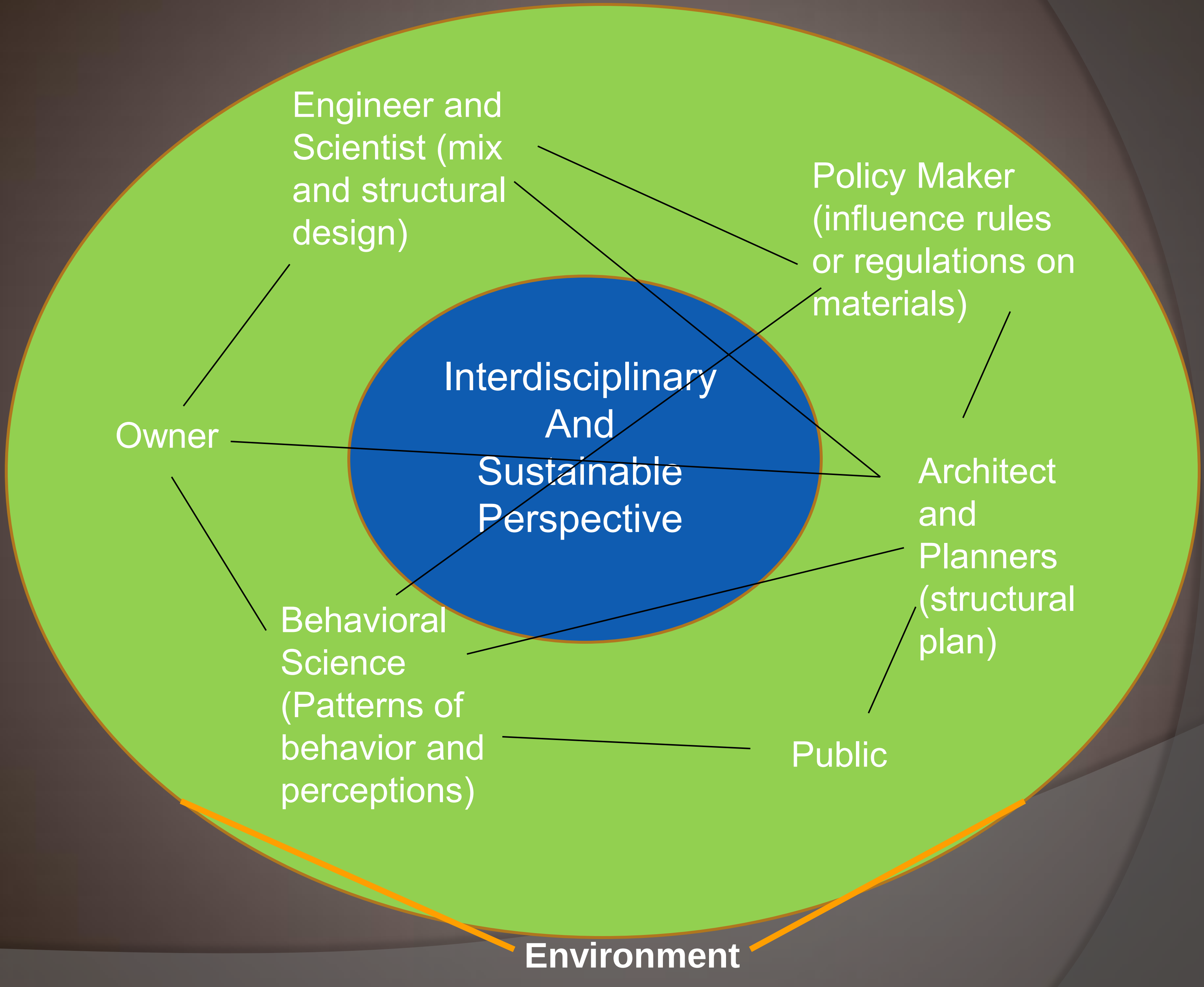
- Large replacements of cement by fly ash can generate 15% to 35% less heat compared to OPC at early ages

Source: Headwaters, 2005

Uncertainties in Literature

- Curing in dry conditions versus humid conditions
- How much will a dense fly ash concrete sample affect thermal conductivity?
- Much of the literature indicates that aggregate has the greatest effect on temperature.
- Is there a need for more field analysis?

Application of Thermal Results

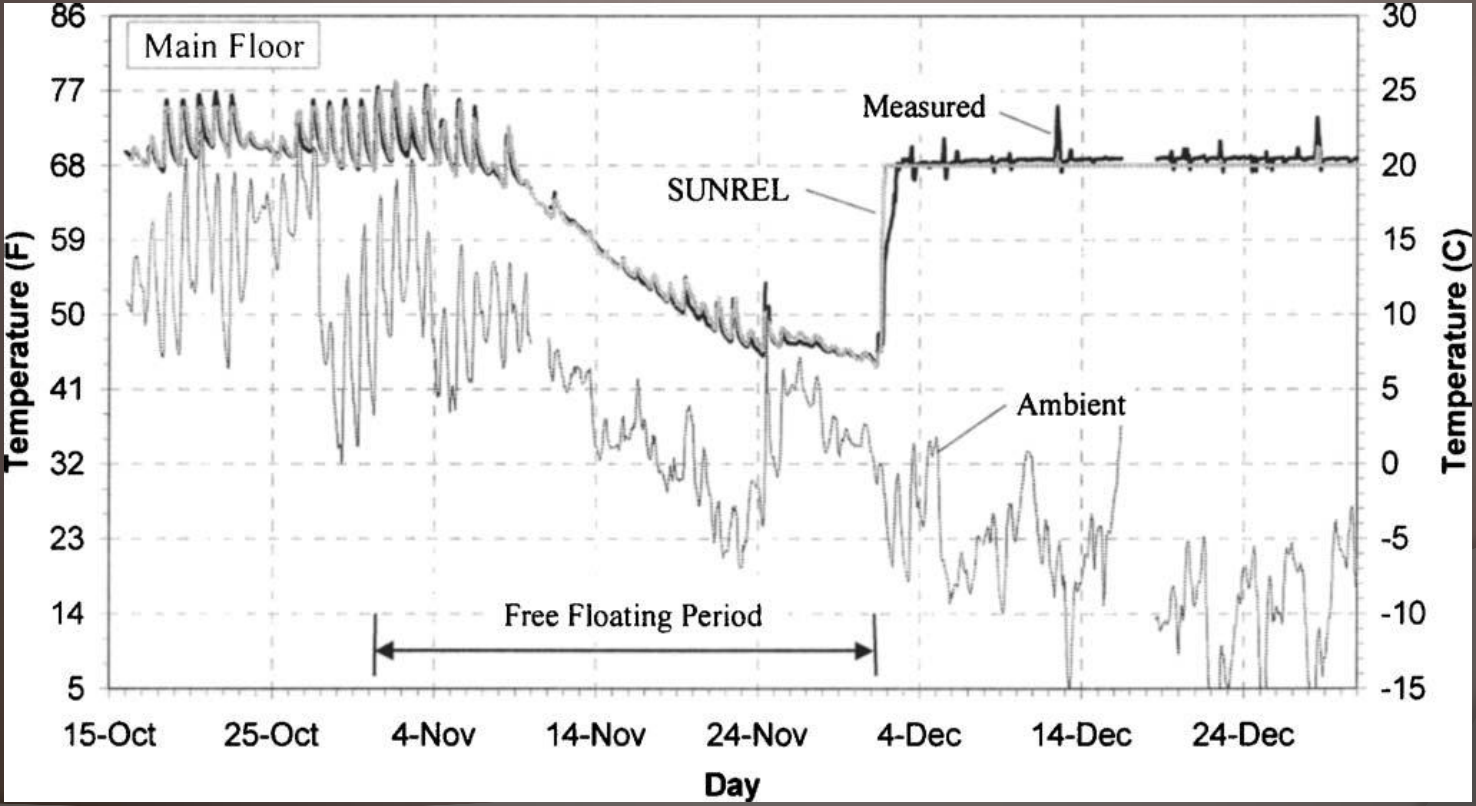

Engineer and Scientist (mix and structural design)
Policy Maker (influence rules or regulations on materials)
Interdisciplinary And Sustainable Perspective
Owner
Architect and Planners (structural plan)
Behavioral Science (Patterns of behavior and perceptions)
Public
Environment

Building and Material Performance

- Simulate energy performance of two buildings
  - Collaboration Dept. of Architecture
  - Use SUNREL program (developed by NREL)
    - Small buildings
    - Solar loadings
    - Input material heat capacities, thermal conductivities
  - Predict temperatures for walls, floors, etc.

Building and Material Performance

- Example of SUNREL results (recycled plastic aggregate concrete building)



Source: Elzafraney, Sroushian, Deru, 2005

Building and Material Performance

- Based on Literature
  - Compare (OPC vs. HVFA)
  - Be familiar with material performance
    - Early age – fresh properties
    - After curing – hardened properties
  - Establish an environment (arid to semi-arid)
    - Mix design (w/c, amount of materials)
    - Curing
    - Long term performance
  - Transfer knowledge to small field demo
- Investigate HVFA residential construction

Building and Material Performance

- Mix Design
  - Design and optimize 3000 - 4000 psi (20.7 – 27.6 Mpa) mix (HVFA mix)
  - Study heat evolution during various curing conditions and methods
    - Temperatures 100-120^{o}F (37.8^{o}C-48.9^{o}C)
    - Placement procedures (vibration vs. hand compaction)
    - Material temperatures (shading vs. sun exposure)
    - Curing materials (plastic sheathing vs. burlap)

Building and Material Performance

- Quantitative and Qualitative Tests
- Fresh Concrete Properties
  - Air content (ASTM C231)
  - Slump (ASTM C143)
  - Density (ASTM C138)
- Hardened Concrete Properties
  - Compressive strength (ASTM C39)
  - Flexural Strength (ASTM C78)
  - Splitting Tensile Strength (ASTM C496)

Building and Material Performance

- Small field Demo
  - Construct two buildings 4ft H x 6ft L x 8 ft W (1.2 m x 1.8 m x 2.4 m)
  - Main construction material HVFA concrete
  - Short term monitoring
    - Location of construction (simulated ambient temps or actual ambient temps)
    - Cooling the buildings
    - Evaluate interior temps and electric power use

Some Expectations

- Early Age
  - Curing – low heat of hydration but high evaporation, strength loss
  - Workability – maintain lower w/cm ratio for HVFA
- After Curing
  - Non-uniform distribution of hydration products – weak zones (source: Mindness, S., Young, J. F., & Darwin, D., 2003).
  - Thermal Cracking may be present

Initial Tests and Results

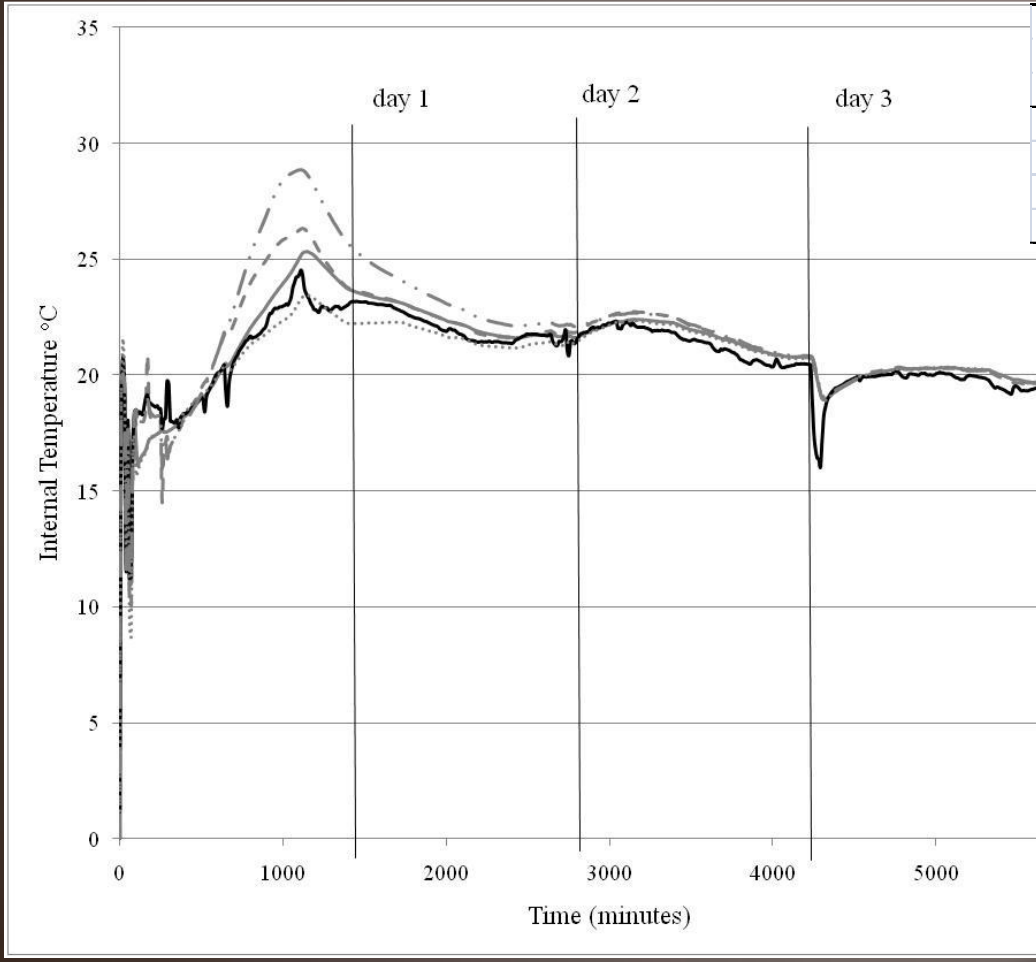
Ambient Test

- Mix design
  - 4200 psi (30 Mpa)
  - 0.4 w/cm
  - OPC vs. 50% FA concrete
  - Air Entrained 4% to 6% air content
- Evaluate
  - Compressive strength
  - Heat of hydration

Ambient Test

- Instrumentation

Ambient Results



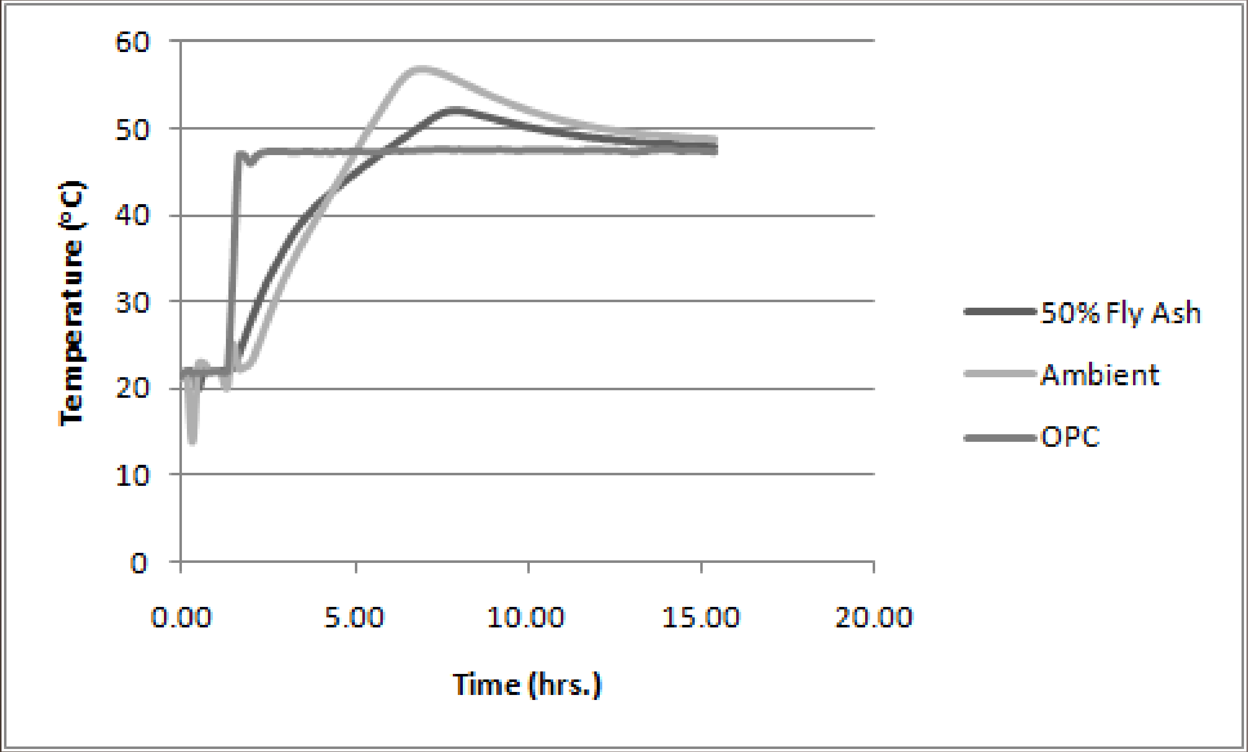
Time (days)	Average Compressive Strength			
	(psi)		(MPa)	
	50% FA	OPC	50% FA	OPC
3	2779	4859	19	36
7	3239	5306	22	37
28	4945	6830	34	47
56	6451	7048	44	49

Largest difference between OPC and FA is 19%

Oven Test

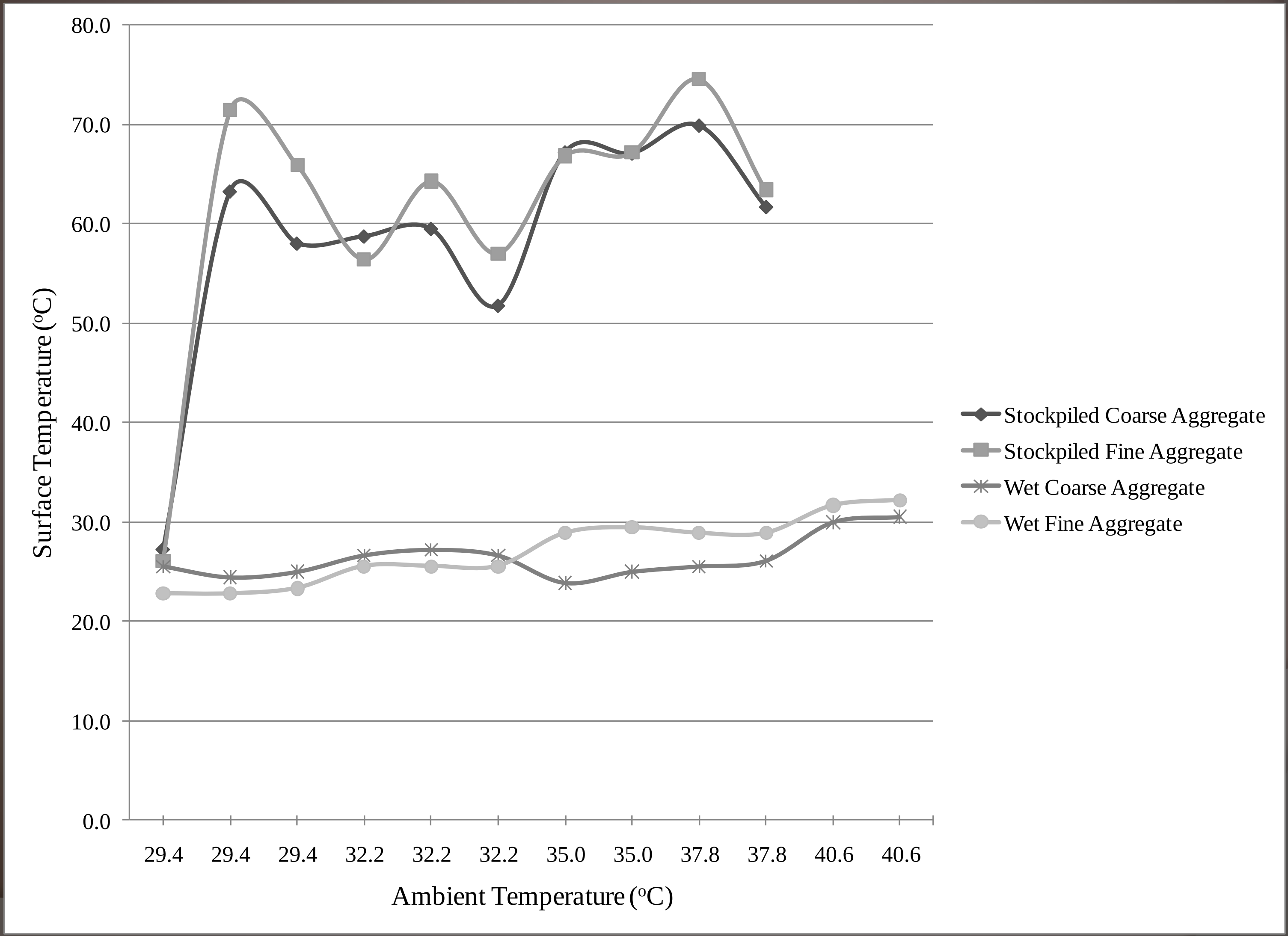
- Mix design
  - 4200 psi (30 Mpa)
  - 0.4 w/cm
  - OPC vs. 50% FA concrete
  - No air entrainment
- Evaluate
  - Compressive strength
  - Heat of hydration

Oven Results



5 % difference in peak of hydration
12% difference between FA and ambient
17% difference between OPC and ambient

Potential influence of aggregate



Conclusion

- HVFA potential benefits in arid to semi-arid environments
- Thermal properties of HVFA could be a sustainable motivation
- Not clear whether HVFA concrete is used in residential construction
- Building performance of HVFA concrete structure could be communicated among a broad audience
- Initial results can le