Smart Materials for Smart Cities

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SHCC 4: Strain-Hardening Cement-Based Composites, Dresden, Germany

Victor C. Li
E. Benjamin Wylie Collegiate Professor
University of Michigan, Ann Arbor
Smart cities deserve smart materials
Civil infrastructure is vulnerable to natural hazards

Aftermath of 2008 Sichuan Earthquake
Concrete infrastructure lacks durability
Civil infrastructure has large environmental impacts

- Natural: 9%
- Metals: 6%
- Polymers: 1%
- Ceramics (dominated by concrete): 84%
Concrete bears load only, & nothing else
Smart materials inspired by nature

Biological system possesses multifunctionality:
Super strong and ductile, Self-sensing, Self-healing, Self-thermal adaptive
Extreme damage tolerance
ECC suppresses brittle fracture and crack induced infrastructure deterioration.

High compressive strength but brittle.
ECC is most ductile concrete material in use

Load capacity maintained even at large strains

Crack width stabilized at ~60 µm
Resilient buildings in Japan

- ECC Coupling beam
- RC core wall
- External frame

Designed by Mitsubishi Jisho Sekkei Inc. & Kajima Corp.; Constructed by Kajima Corp.
Durable ECC link-slab in the US

- ECC link-slab
- 225 mm x 5.5 m x 20 m
- 2005 Grove St. Bridge Demo
- ECC link slab
- Durable ECC link slab in the US
Ductility and durability of ECC leads to infrastructure sustainability

~40% reduction in primary energy consumption and CO₂ emissions
Thermal Adaptive functionality
Thermal resistance and thermal capacitance reduces and delays peak temperature.

40% of home energy use is devoted to space heating and cooling.
Increasing thermal capacitance with phase-change materials

Paraffin micro-encapsulated in PMMA. Melting temp: 73°F
Increasing ECC thermal capacitance with phase-change materials

Estimated 1-2°C and 2 hour delay of peak temperature is feasible

Desai et al, 2013
Self-sensing functionality
ECC serves as a structural material and as sensors for health monitoring.

Piezoresistivity allows correlation between resistivity and cracking/strain.
Resistivity increase with strain/damage

Resistivity (kOhm-cm)

Stress (MPa)

Strain (%)
Direct reading of damage evolution during strain hardening

Lynch et al, 2009
Self-healing Functionality
ECC self-heals – just let it rain
Rehealing function maintained after repeated damage cycles
Self-healing robustness – natural environment

Herbert and Li, 2013
Conclusions

• Smart cities demand smart infrastructure with dramatically enhanced resiliency, durability, sustainability, and intelligence

• Inspired by nature, ECC provides a materials design platform to meet these needs

• ECC can embody multi-functionalities, including thermal adaptability, self-healing and self-sensing in a single material
Harmonious built and natural environment