Sustainable 3D-Printed Concrete Sidewalks with Low Heat Storage

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Outline

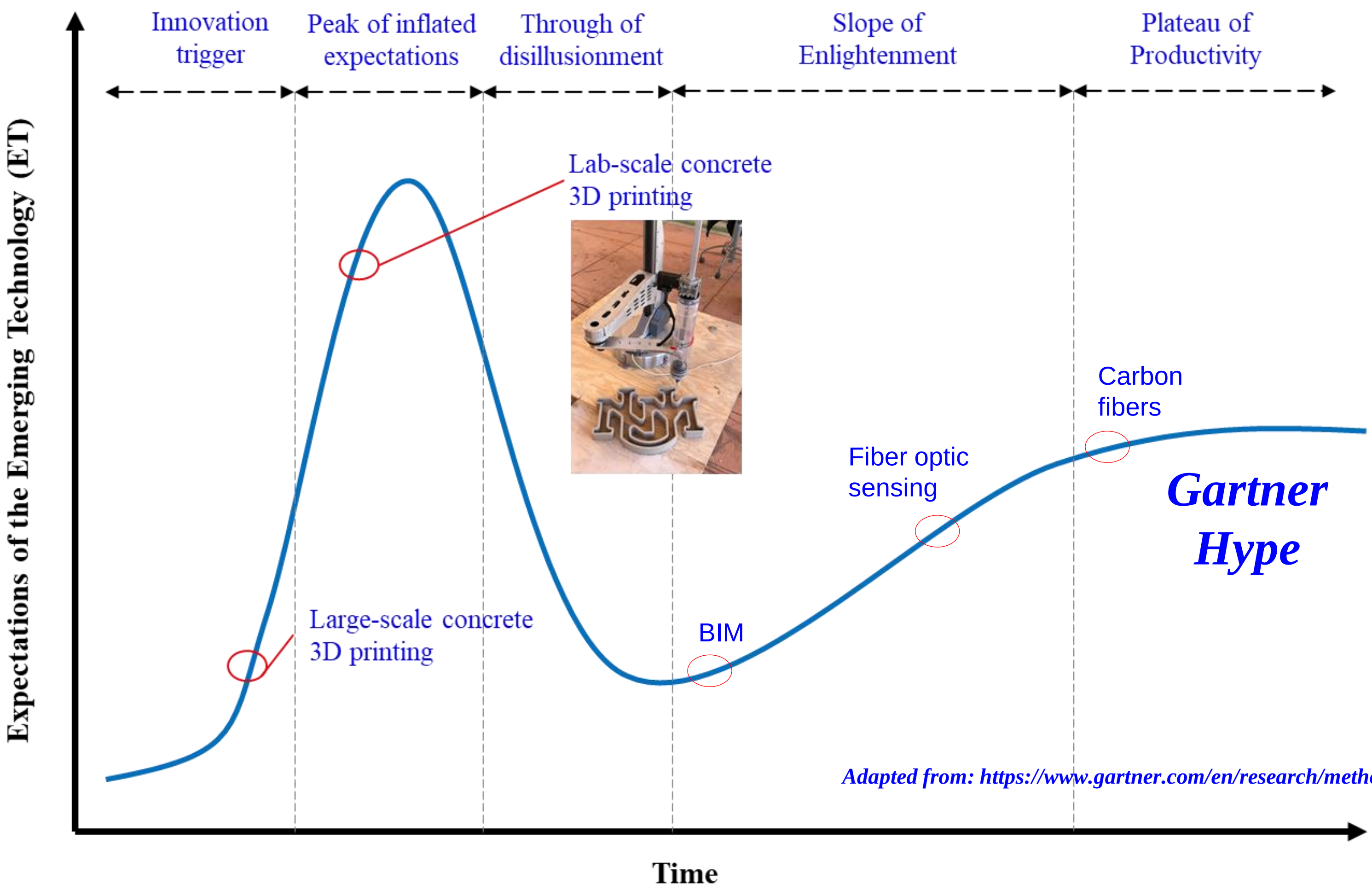
- Goal & Hypothesis
- Concrete 3D-printing as an emerging technology
- 3D-Printed Concrete Variables
- 3D-Printed Concrete Rheology
- 3D-Printed Concrete Sidewalks with Low Heat Storage
- 3D-printed concrete with negative carbon footprint
- Conclusions

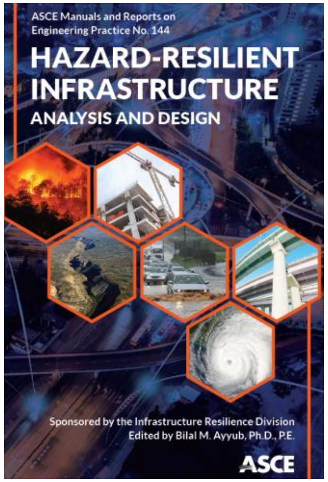
Goal & Hypothesis

Our Goal ***is to engineer 3D-printable concrete with low carbon footprint and improved mechanical and durability properties leading pathway towards sustainable infrastructure and carbon neutrality.***

Our Hypothesis: ***Using nanomaterials & 3D-printing technology, we can create a new generation of concrete with superior properties and reduced carbon footprint.***

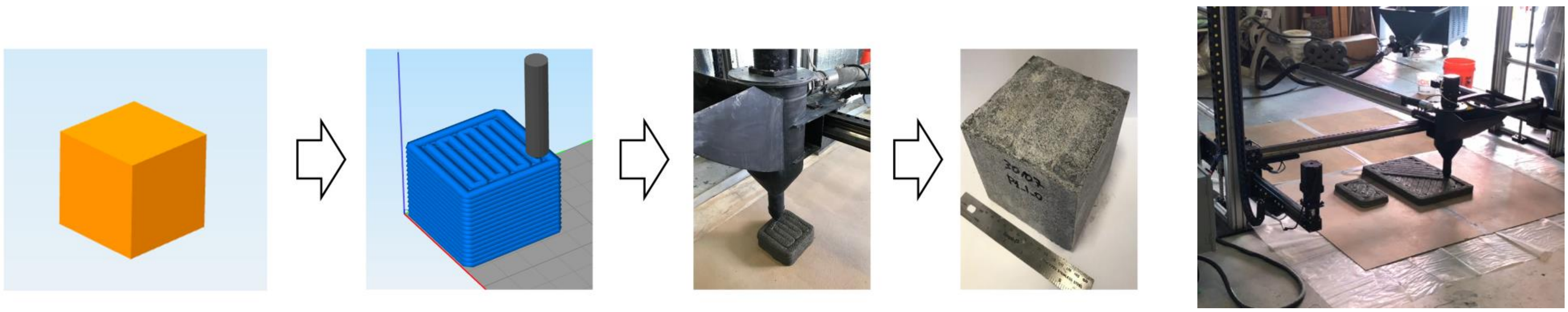
Concrete 3D Printing as an Emerging Technology





Reda Taha, M. et al. "Emerging Technologies for Resilient Infrastructure – A Conspectus and Roadmap", ASME-ASCE Journal of Risk and, Part A: Civil Engineering, Vol. 7, No. 2, 03121002, 2021.
to system resilience.

3D printing process



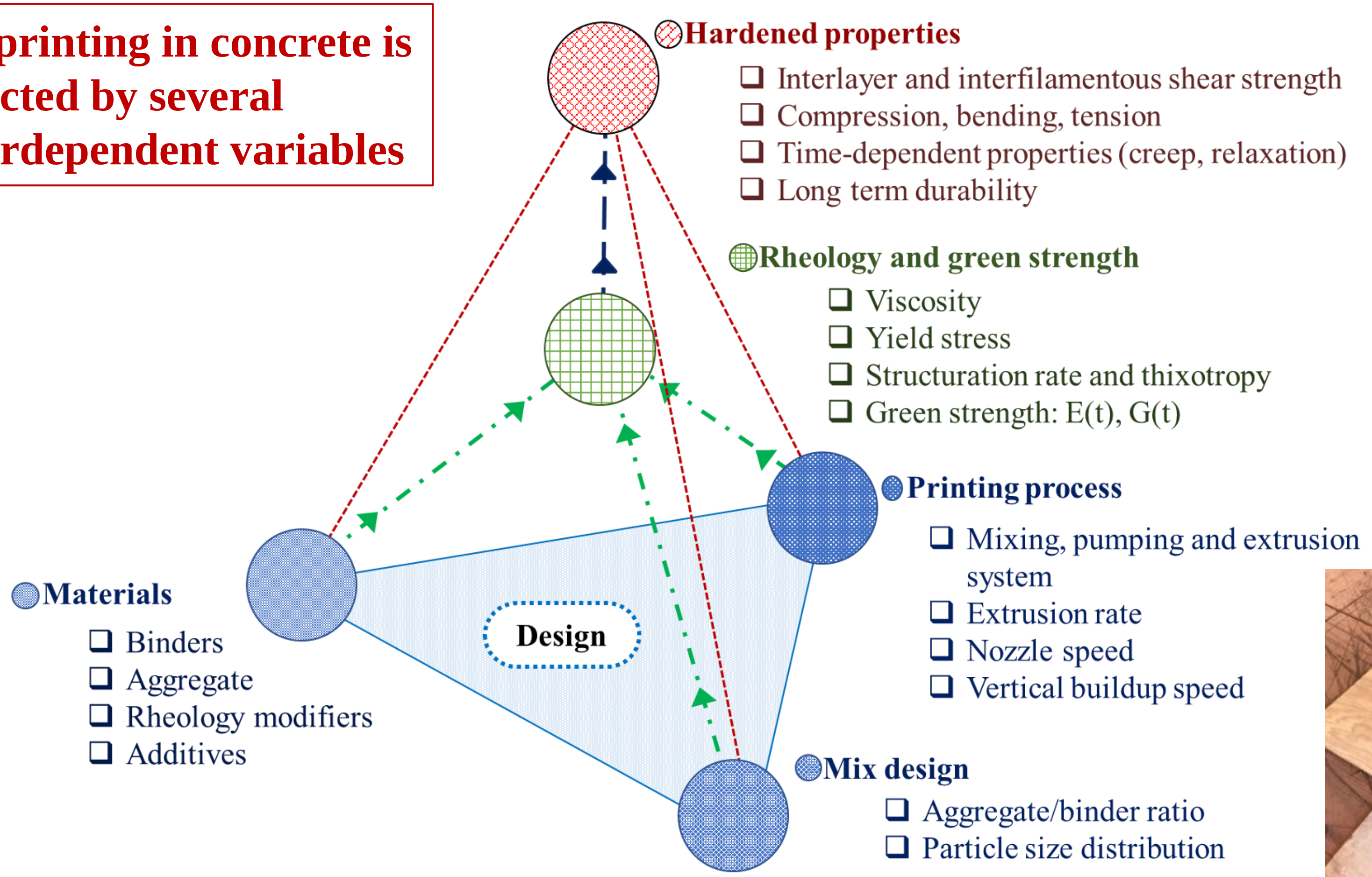
Design and simulation

Lab scale printing and testing

Large scale implementation

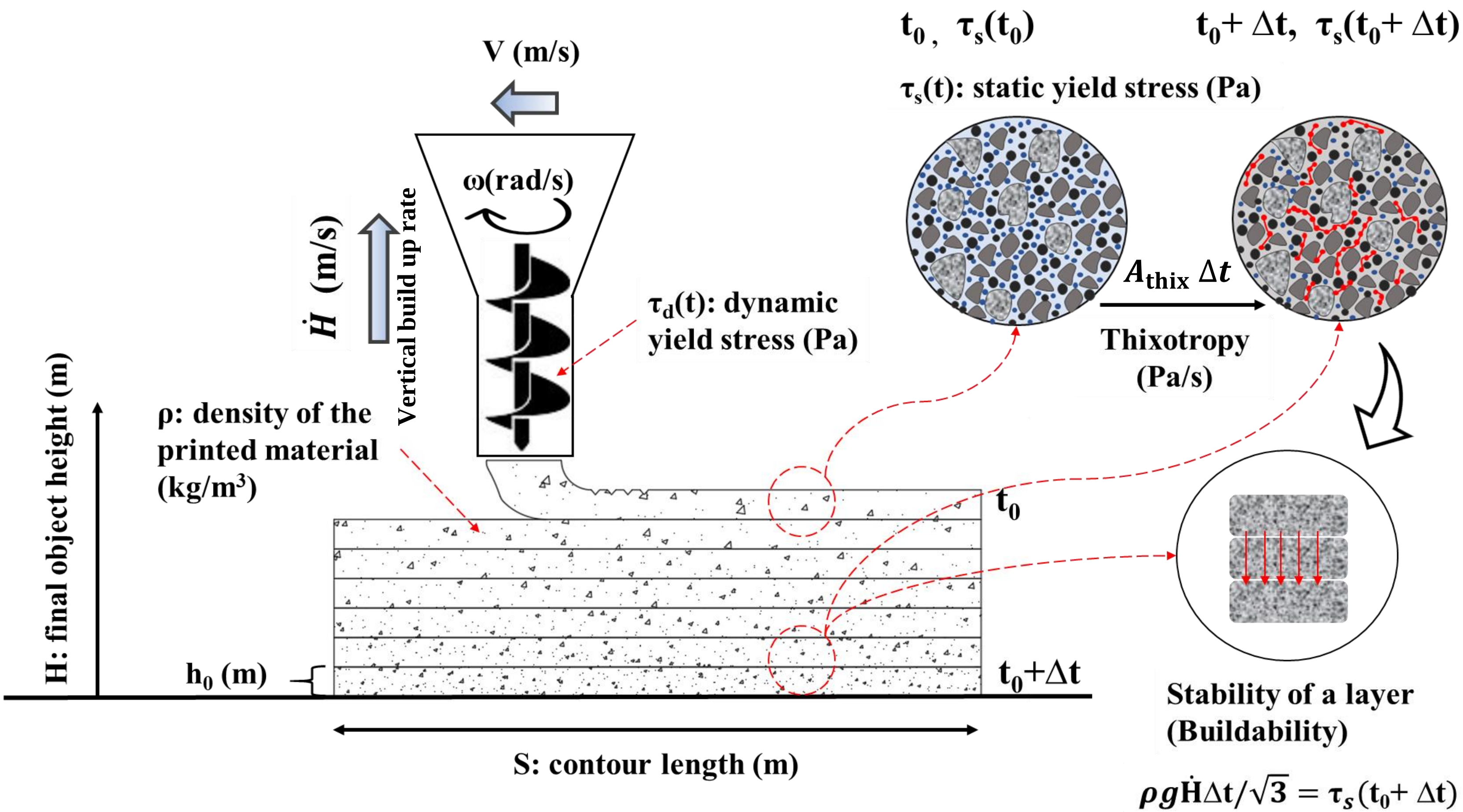
3D-printed Concrete – Variable Interdependency

3D printing in concrete is affected by several interdependent variables



Murcia, D. H., Genedy, M., & Reda Taha, M. (2020). Construction and Building Materials, 262, 120559.

Rheology of 3D-Printed Concrete



Heras Murcia, D., Abdellatef, M., Genedy, M., Reda Taha, M. M. "Rheological Characterization of 3D Printed Polymer Concrete", ACI Materials Journal, Vol. 118, (6), pp. 189-201, 2021.

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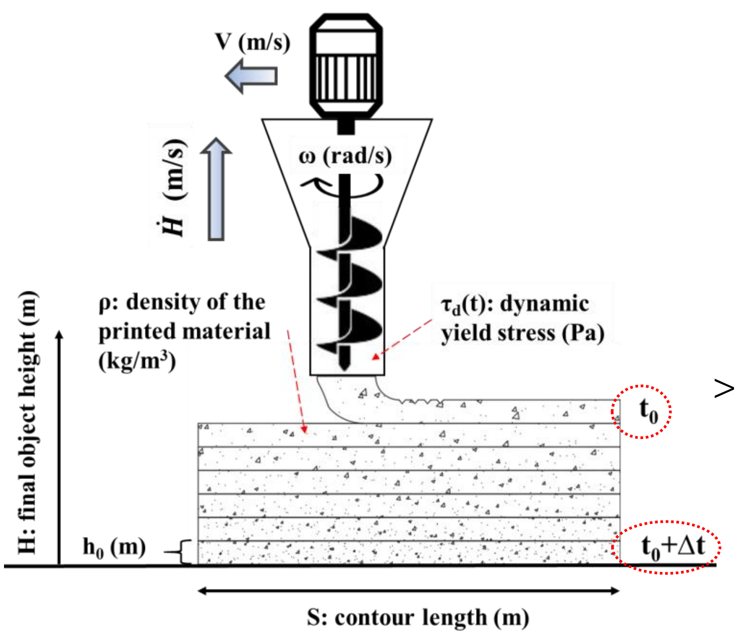
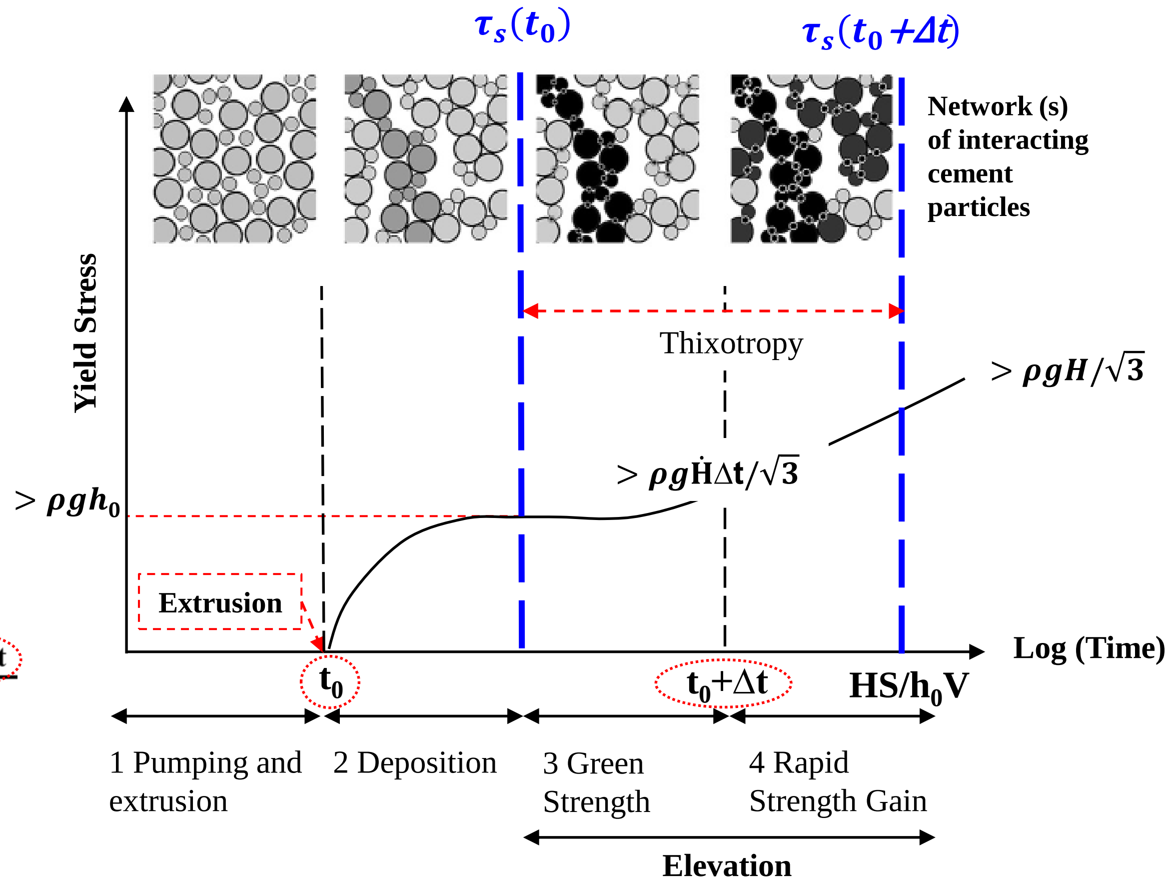
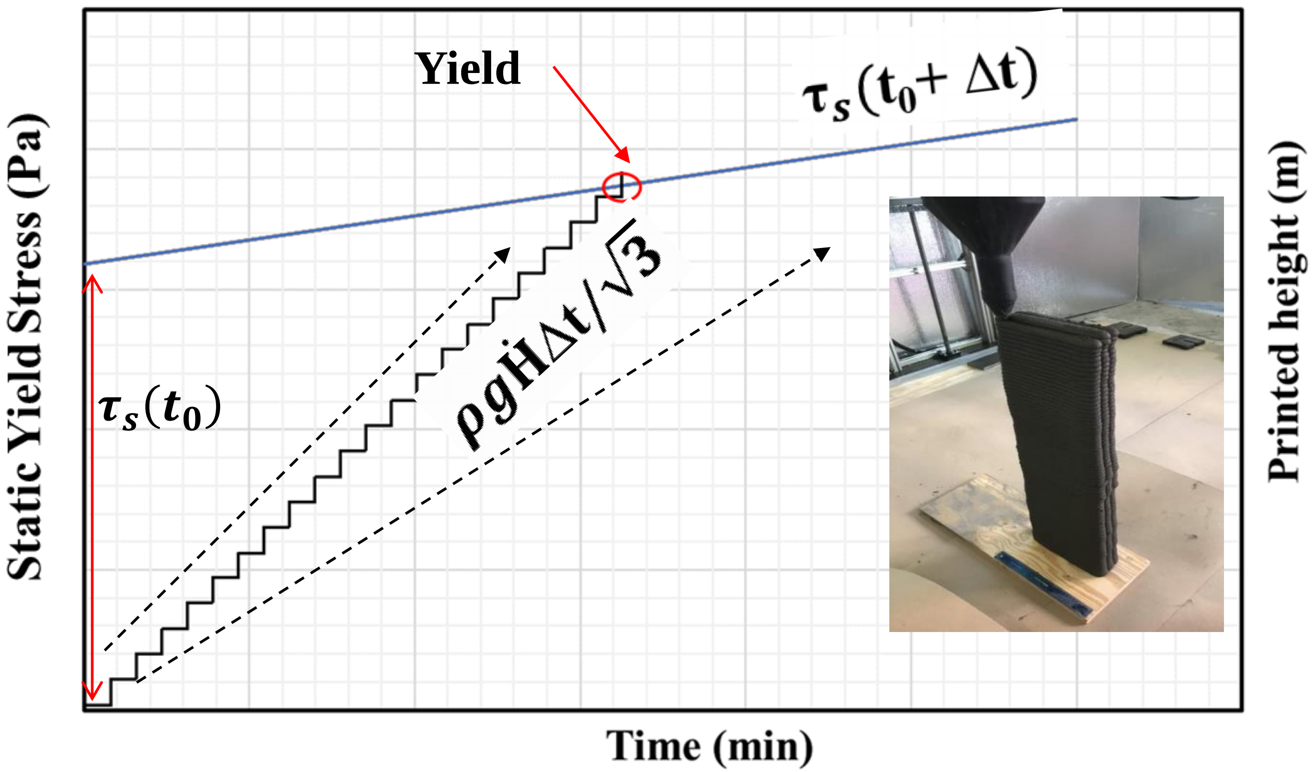




Heras Murcia, D., Abdellatef, M., Genedy, M., Reda Taha, M. M. "Rheological Characterization of 3D Printed Polymer Concrete", ACI Materials Journal, Vol. 118, (6), pp. 189-201, 2021.

Buildability of 3D-Printed Concrete



$$\tau_s(t_0) + A_{thix}\Delta t = \rho g H/\sqrt{3} \quad \rightarrow \quad A_{thix} > \dot{H}(\rho\, g/\sqrt{3} - \tau_s(t_0))$$

Gravitational extensional stress

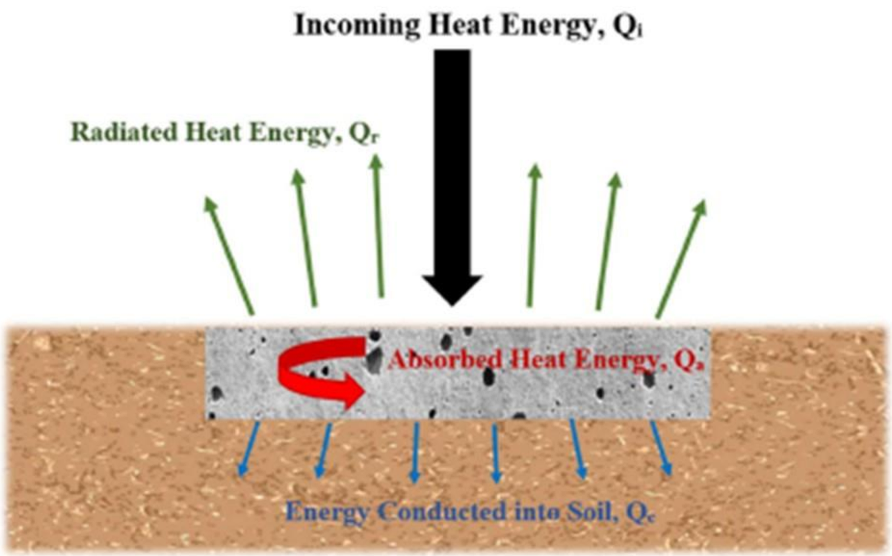
3D-Printed Concrete Sidewalks with Low Heat Storage

- Our objective is to ***design a sidewalk that can be built using recycled and less energy- and carbon-intensive materials*** with the thinnest possible thickness (in order to reduce material, use and limit heat storage capacity).

- By revisiting the materials and techniques that cities and towns use to build sidewalks, we believe ***it is possible to identify more durable, environmentally sustainable, and cost-effective approaches than are commonly used today***.

- ***3D printing provides flexibility and automation*** to construction processes. With the use of 3D technology, ***complex shapes and design geometries*** can be introduced that would otherwise not be possible with traditional casting methods.

Heat storage of concrete sidewalks



Schematic of Energy Balance

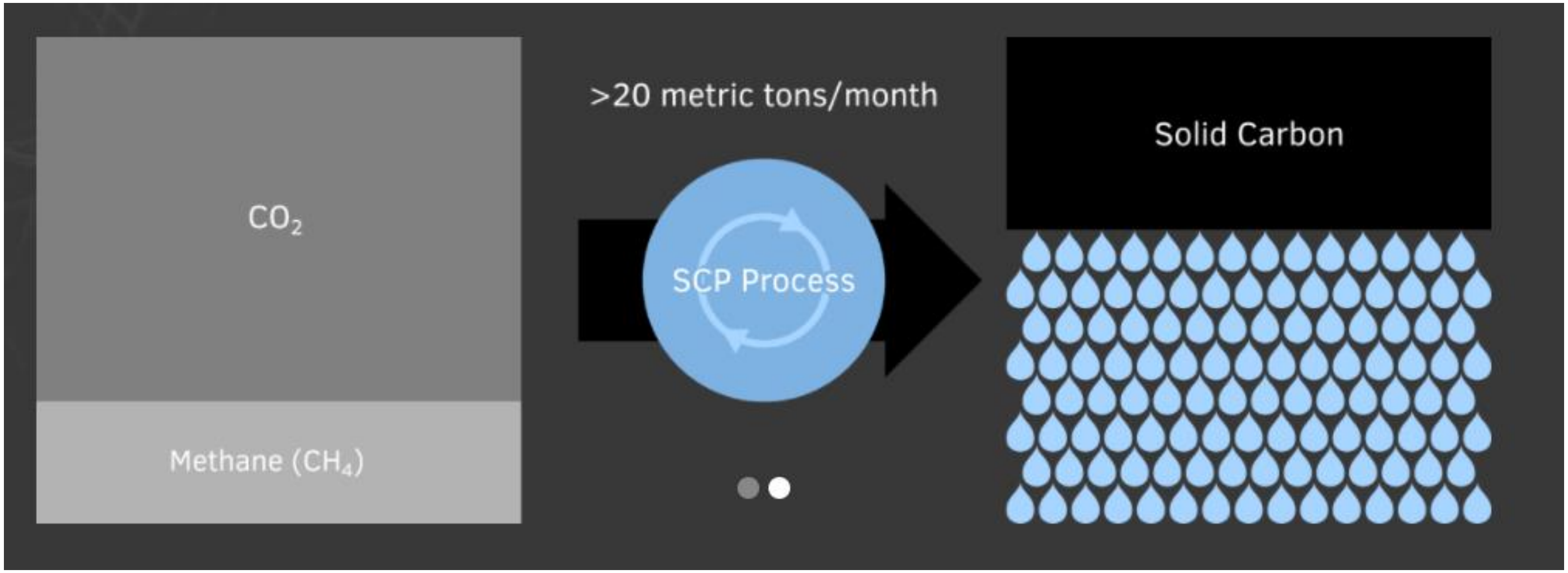
$$Q_i = Q_r + Q_a + Q_c$$

$$Q_r = e * \sigma * A * t * T_{con}^4$$

$$Q_a = e * \sigma * A * t * T_{air}^4$$

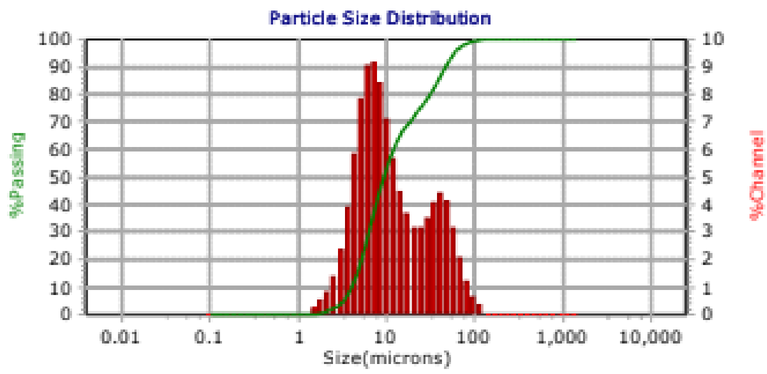
$$Q_c = \frac{k * A * t * (T_{top} - T_{under})}{d}$$

CO2 Sequestered Carbon Black

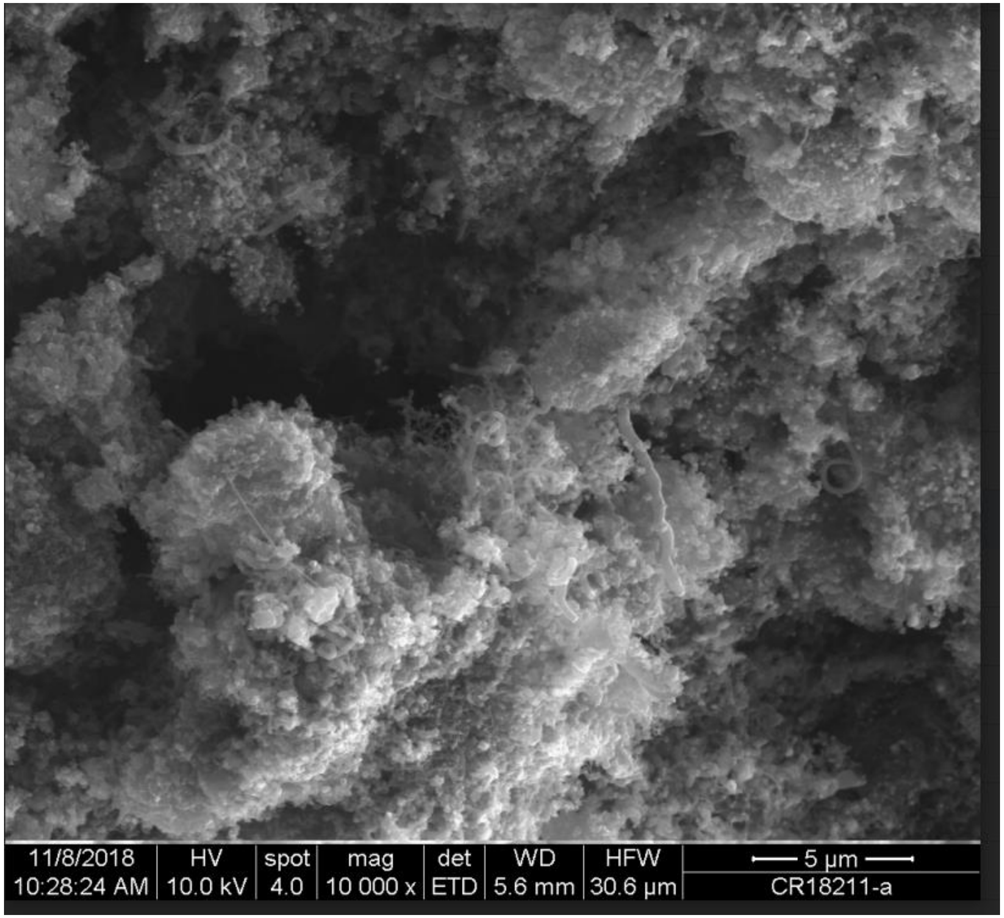


- Patented process produces solid carbon black from sequestered Carbon Dioxide (CO_2) and Methane gas (CH_4).
- Through a multi-step process, these reactants are heated, pressurized and used to produce solid carbon black particles.

CO2 Sequestered Carbon Black



Specific gravity is 2.1 g/cc



Concrete Mix

Control Mix

Cement	150
Fly Ash	170
Slag	300
Silica Fume	78
Aggregate	1171
Water	210

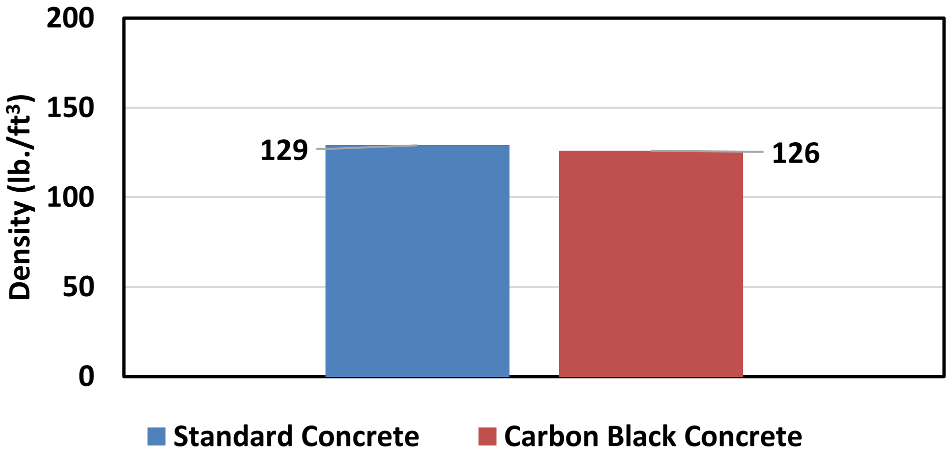
Replace aggregate and/or binder with carbon black particles

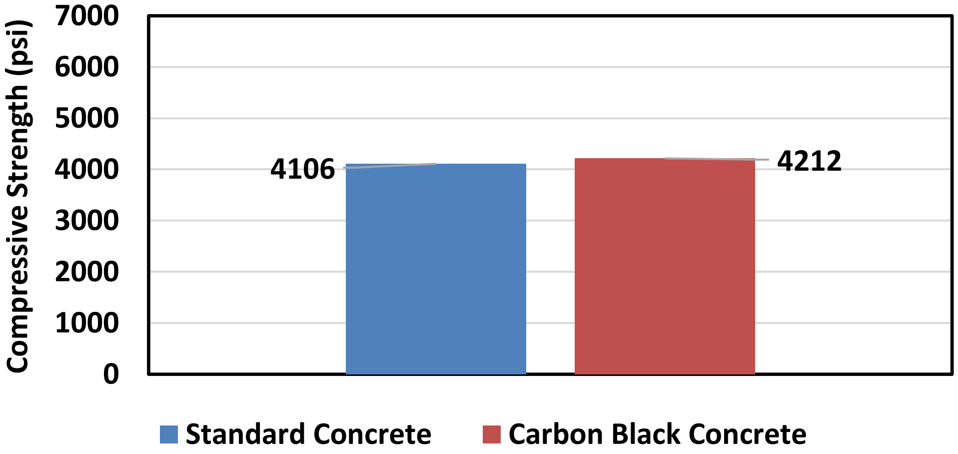
Mixing

Reda Taha, M. M. & Heras Murcia, D. Concrete with Negative Carbon Footprint Using CO2 Sequestered Carbon Black, US Provisional Patent Filed, March 2022

Concrete Testing

Testing

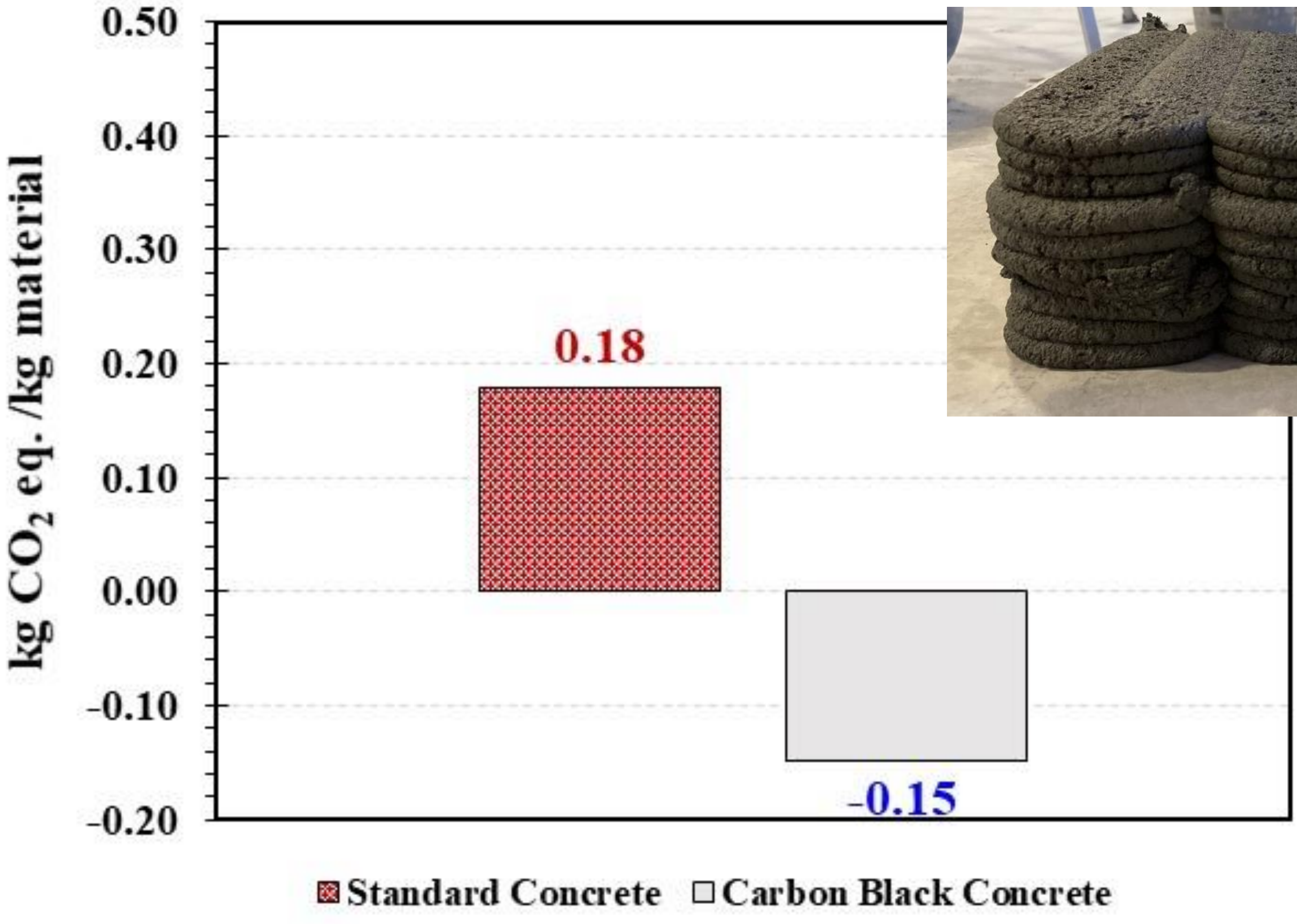




3D-Printing of Concrete Mixes w/CB & Rubber Crumbs

3D-printing of carbon negative concrete mixes incorporating carbon black & rubber crumbs

Carbon footprint of concrete for sidewalks



Potential amount of sequestered CO_2

- ***The amount of concrete produced per year in the US is about 10B tons.***

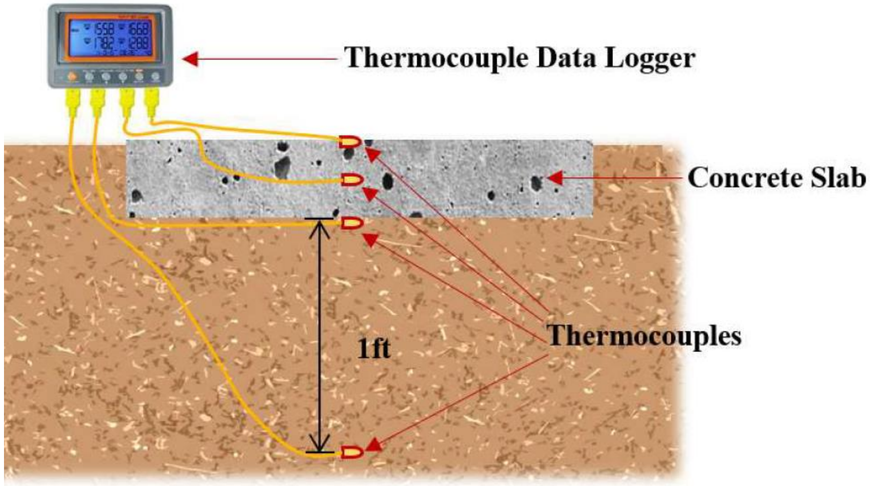
- Assuming a typical concrete mix by weight is aggregate and assuming 10-30% replacement of aggregate with CO2 sequestered carbon black.

- 10.0 B tons annual concrete ➔ **0.7-2.0 B tons of solid carbon black**

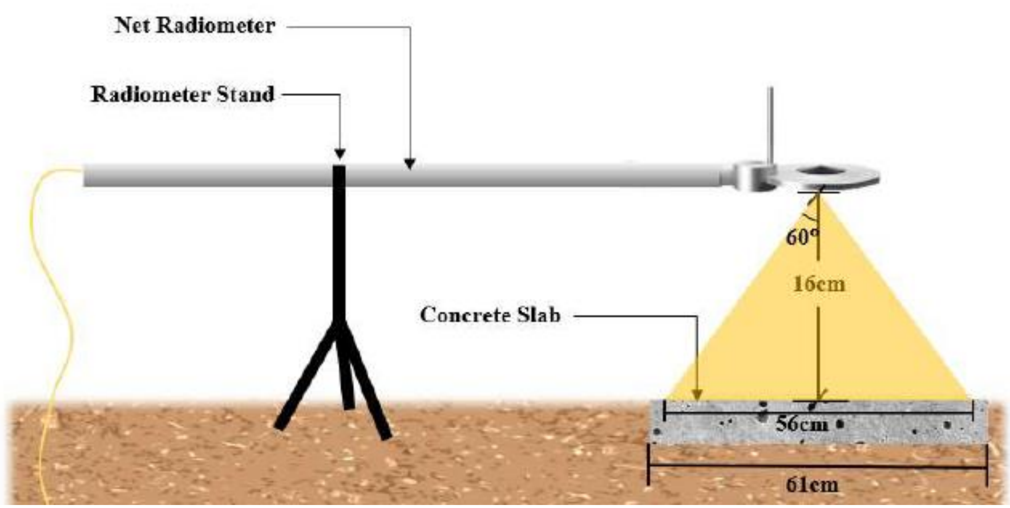
- In the Noyes process, **3.7 tons of CO_2** ➔ is used 1.0 ton of solid carbon black

    - ➔ **2.5-7.5 tons of CO_2 sequestered into 3D-printed concrete annually.**

Thermal conductivity testing of concrete sidewalks

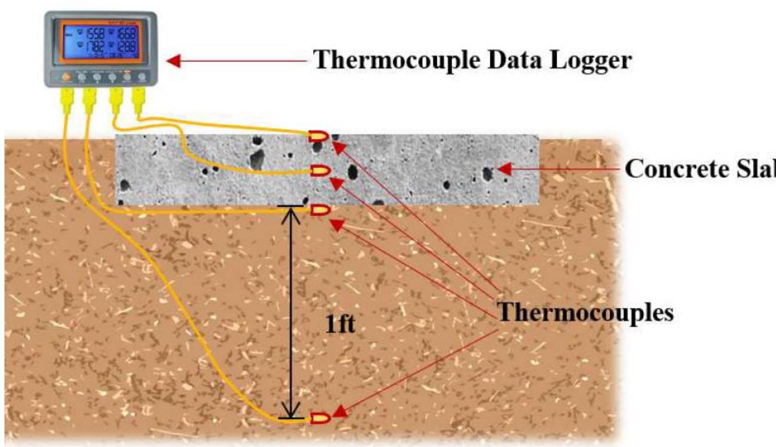


Thermal conductivity testing of concrete sidewalks



Schematic of Solar Irradiance testing setup

Thermocouple setup in heat capacity slabs



Conclusions

- ***Carbon black from sequestered CO_2*** has been investigated to be used ***in 3D-printed concrete***.
- Concrete mixes incorporating solid carbon black particles showed ***compressive strength of 4000 psi (30 MPa)*** which is very suitable for concrete sidewalks.
- The carbon black tends to ***retain water which makes the flow properties variable with time***. This can affect ***concrete thixotropy and buildability*** and requires careful mix design for 3D-printing.
- For applications with low strength requirements (e.g., sidewalks), ***replacing part of the cement/pozzolanic binder with carbon black is being investigated.***
- The thermal properties of the material for sidewalk applications are being measured. ***Preliminary data shows concrete including carbon black to have low heat storage compared with conventional concrete mixes.***
- Other important properties of concrete sidewalks including carbon black ***(e.g., shrinkage and freeze-thaw durability)*** are also being tested.

Selected Journal Publications by Taha's Research Team

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Starr, J., Soliman, E., Matteo, E. N., Dewers, T., Stormont, J. C., Reda Taha, M. M., "Mechanical Characterization of Low Modulus Polymer-Modified Calcium-Silicate-Hydrate (C-S-H) Binder", ***Cement & Concrete Composites***, 124, 104219, **2021.**

Vemuganti, Shreya, John C. Stormont, Laura J. Pyrak-Nolte, Thomas Dewers, and Mahmoud Reda Taha. "Cement sensors with acoustic bandgaps using carbon nanotubes." ***Smart Materials and Structures*** **2021.**

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Vemuganti, S., Chennareddy, R., Riad, A. and Reda Taha, M. M. "Pultruded GFRP Reinforcing Bars Using Nanomodified Vinyl Ester", ***Materials***, 13, 5710; https://doi:10.3390/ma13245710, **2020.**

Heras Murcia, D., Genedy, M. and Reda Taha, M. M. "Examining the Significance of Infill Printing Pattern on the Anisotropy of 3D-Printed Concrete" ***Construction & Building Materials,*** 262, 120559, **2020.**

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Genedy, M., Chennareddy, R., Soliman, E., Kandil, U. F., Reda Taha, M.M. "Improving Shear Strength of GFRP Bolted Lap Joints Using Carbon Nanotubes", ***Journal of Reinforced Plastics and Composites***, Vol. 36, No. 13, pp. 958-971, **2017.**

Acknowledgment

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THANK YOU

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