CONCRETE INNOVATIONS

LEARNING CENTER | AWARD PROGRAM

Biochar concrete: carbon reduction, mechanical enhancement and commercial viability

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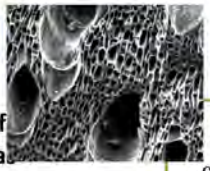
WHAT IS BIOCHAR?

Biochar is a residue from thermal decomposition (e.g. pyrolysis) of organic material (biomass such as wood, manure or leaves) under limited supply of oxygen (O_2), and at relatively low temperatures (<700°C).



WHY BIOCHAR?

Pores adsorb carbon dioxide and traces of oxides of nitrogen

Means of waste reduction and recycling

Reduction of up to 12% of global anthropogenic emission annually (Woolf et al., 2010)

Reduction of net life cycle greenhouse gas emissions by about 870 kg CO_2 equivalent (CO_2-e) per ton dry feedstock (about 300kg of biochar)

PIONEERING WORKS IN BIOCHAR CONCRETE

- **Choi et al. (2012)** found that a dosage of 5% by weight of cement (wt.%) of hardwood biochar improved the compressive strength of mortar by 10-12%.
- Schmidt (2014) then initiated several onsite demonstration projects in which biochar-containing wall plaster was used in several locations in the Ithaka Institute in Sion, Switzerland.
- Ahmad et al. (2015) studied bamboo biochar produced at 850˚C, at a heating rate of 60 ˚C/min for 1 hour; biochar improved compressive strength of biochar-cement pastes by 40-50%, toughness by 103% and flexural strength by 66%.
- Restuccia and Ferro (2016) found adding biochar up to 1 wt.% increased the fracture energy of cement-based composites by 61%

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Important Milestones & Lessons Learnt in Biochar Mortar/Concrete

- 2012-2016: *Filler effect and improvement to mechanical properties*. Pioneering works.
- Starting 2017: understanding of how biochar affects microstructure of mortar, water permeability, mechanical strength and carbon sequestration

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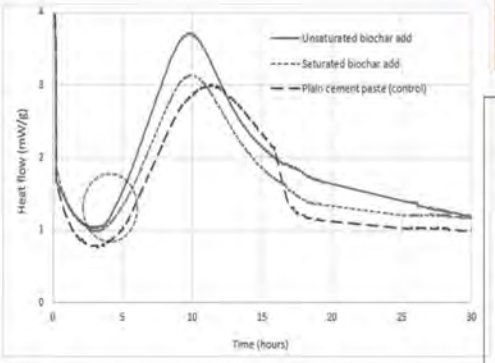
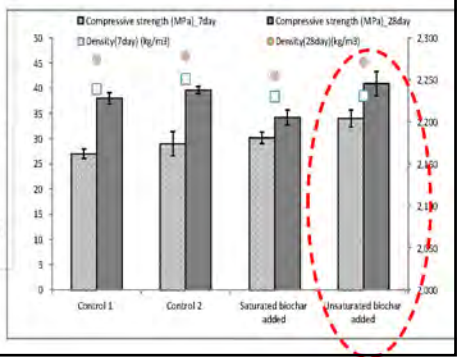
Investigating Biochar's Effect of Carbon Sequestration on the Mechanical Hygromechanical Properties of Biochar Mortar (1 of 2)

Objective:

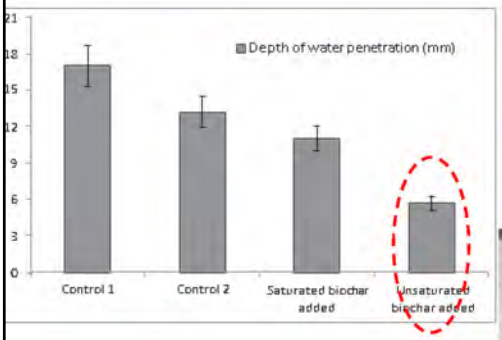
Understand how calcium carbonate formation due to sequestered carbon dioxide in biochar affect the strength and water permeability of mortar.





Source:
Gupta, S., Kua, H.W. and Low, C.Y., 2018. Use of biochar as carbon sequestering additive in cement mortar. Cement and concrete composites, 87, pp.110-129.

Investigating Biochar's Effect of Carbon Sequestration on the Mechanical Hygromechanical Properties of Biochar Mortar (2 of 2)



- **Saturated biochar particles act as centers of carbonation enhancement. But excessive calcite formation can cause decalcification of matrix *(Johannesson & Utgenannt, 2001)***
- **Unsaturated biochar reduces water penetration by ~57% and increases compressive strength by ~16%**

Important milestones in biochar mortar/concrete

- **2012-2016**: *Filler effect and improvement to mechanical properties*. Pioneering works.
- **Starting 2017**: understanding of how biochar affects microstructure of mortar, water permeability, mechanical strength and carbon sequestration
- **Starting 2018:**
  - *Better understanding of other contributions of biochar in mortar/concrete.* E.g. effects of biochar particle size and pore size, shrinkage; "reservoir" effect (using pre-soaked biochar)

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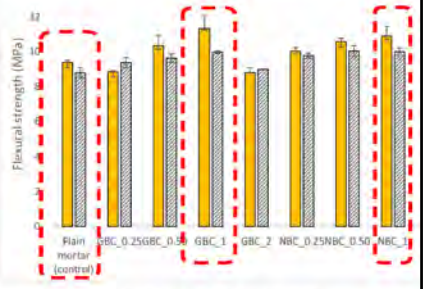
Effect of Particle/Pore Size and Dosage of iochar on Fresh and Hardened Properties of Cement Morta

bjective: explore influence of biochar particle/pore size on rheology, hydratic netics, strength and permeability of cement mortar.

zes: manually ground (NBC; d_{50} = 10μm) and ball-milled (GBC; d_{50} = 0.92μm)

	BET surface area (m^2/g)	Micro-pore surface area (m^2/g)	BJH pore volume (desorption) (cm^3/g)	Average pore diameter (MIP) (μm)
BC	196.92	142.88	0.0123	3.80
BC	227.13	150.74	0.0198	0.013

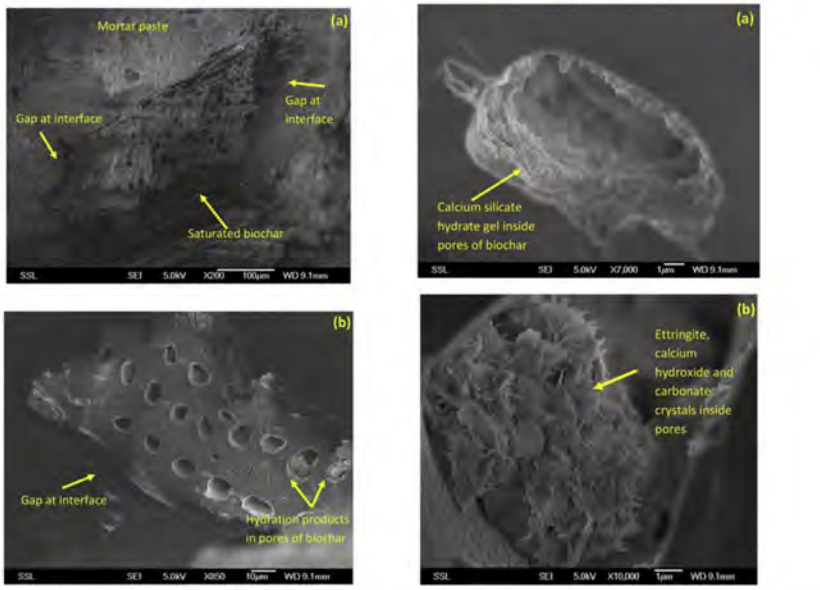
	Mist curing	Air curing
1 day strength (MPa)	28 day strength (MPa)	28 day strength (MPa)
39.74 (1.94)	64.80 (2.63)	63.34 (1.76)
40.64 (1.20)	61.78 (2.68)	58.86 (0.46)
38.51 (3.42)	69.66 (2.49)	66.61 (3.46)
40.97 (1.26)	70.64 (2.23)	66.04 (4.44)
38.61 (2.10)	70.59 (2.51)	65.76 (1.33)
38.57 (0.06)	67.85 (1.56)	60.87 (2.43)
35.97 (3.42)	68.00 (2.04)	63.46 (3.10)
35.89 (1.09)	70.39 (1.67)	67.56 (0.98)
36.60 (0.62)	69.40 (2.10)	56.43 (3.90)
36.48 (0.57)	69.11 (3.10)	54.44 (3.30)



ling reduces particle AND pore sizes of biochar.
ctors play critical roles in determining mechanical ies of biochar mortar.

Source: Gupta, S., & Kua, H. W. (2019). Carbonaceous mic cement: Effect of particle size and dosage of biochar on fr properties of cement mortar. Science of The Total Enviro 962.8

Biochar Pores as Nucleation Surfaces for Hydration Products



Source:
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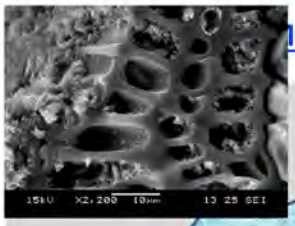
IARY: HOW DOES BIOCHAR HELP?



KEY LESSONS:

1. Small biochar particles act as fillers in air voids.
2. Increase local mortar density, and avoid excess water that leads to air voids upon evaporation.
3. Pores provide additional surface area for water storage and nucleation of cement hydration.
4. Acts as reservoir to diffuse water into mortar mixture to promote hydration.

Important milestones in biochar mortar/concrete

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- **Starting 2018:**
  - *Better understanding of other contributions of biochar in mortar/concrete.* E.g. effects of biochar particle size and pore size, shrinkage; "reservoir" effect (using pre-soaked biochar)
  - ***Application of biochar with other additives.*** E.g. Recycled aggregate concrete (Akhtar and Sarmah, 2018); rice husk ash (Muthukrishnan et al., 2019); UHPC (Dixit et al. (2019)); silica fume (Gupta and Kua, 2018) etc.
- **2019-2021:**
  - ***Biochar mortar as resilient material in harsh conditions.*** E.g. self-healing (Kua et al., 2019); high temperature environment (Gupta and Kua, 2020); resistance in high sulphate and chloride environments (Gupta, Muthukrishnan and Kua, 2021) etc.
  - ***Advanced characterization of biochar in mortar.*** E.g. nano-indentation (Akhtar and Sarmah, 2020)
  - ***Accelerated Carbonation Curing*** (Gupta et al., 2021)

The Way Ahead

- **Biochar for enhancing Accelerated Carbonation Curing**

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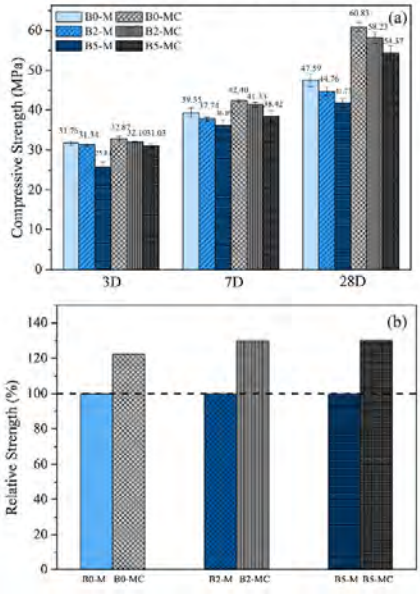
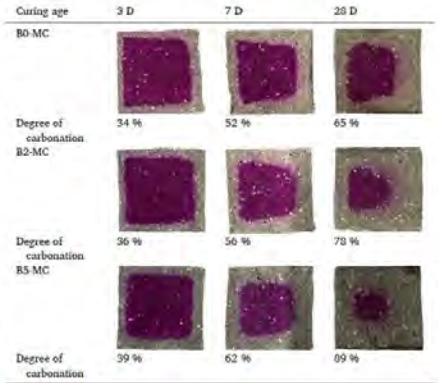
Using Biochar for Accelerated Carbonation Curing





- To date, fewer than 15 articles on using biochar for ACC
- Results show great potential for strength enhancement and C sequestration
- Lacking a unified framework to compare one set of results with others over a long time period.

Source: Yang, X. and Wang, X.Y., 2021. Strength and durability improvements of biochar-blended mortar or paste using accelerated carbonation curing. Journal of CO2 Utilization, 54, p.101766.

The Way Ahead

- **Biochar for enhancing Accelerated Carbonation Curing**
- **Commercial viability**
  - Material standards to ensure uniformity in biochar quality and safety of concrete components (e.g. acceptable level of heavy metals and toxic substances)
  - Appropriate applications and products with competitive prices against incumbent products
    - Blend biochar with other materials to produce composites *better* and *cheaper* than biochar concrete
    - More test-bedding projects are needed


CONCLUSIONS

- Biochar mortar/concrete is a relatively young field
- Last decade has been very productive, with important milestones achieved through the hard work of several teams across the world
- New research and commercial opportunities await us, with key challenges to be overcome

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Introduction

Editor-in-Chief: Wenfu Chen

Scope

Processing and preparation of biochar
Biochar-based materials
Soil and farming
Remediation and conservation
Global climate change
Bioenergy and rural development

Types of article

Review
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