Biochar-based Building Materials

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Join the U.S. Biochar Initiative to promote the sustainable production and use of biochar!

USBI

Building the future from the ground up.™

ithaka institute

AGENDA

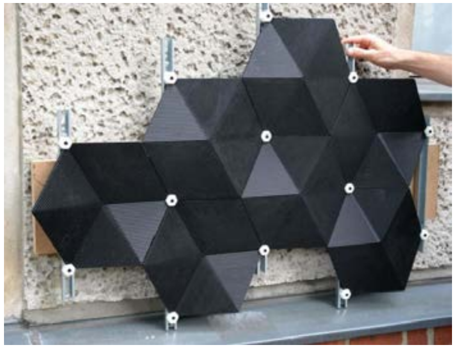
- Where can biochar be used?
- Why use biochar in building materials?
- Where is it happening?
- Which biochar properties matter?
- What does the research say?
- Potential GHG Impact

Where can biochar be used: Maximizing biochar use in the building trade

BUILDING MATERIALS
- Concrete
- Composites
- Drywall
- Insulation
- Tiles
- Infill

HARDSCAPE
- Asphalt - driveways
- Bricks - paths
- Concrete (both)

SOFTSCAPE
- Garden
- Lawn
- Rain Gardens
- Leach fields



Why use biochar?

- Sequestration is not a financially viable reason (yet)
- Low cost, light weight filler that can enhance various properties
- Immobilize toxins
  - In carbonized organic materials (e.g. phytoremediation plants, sludge)
  - From other sources (e.g. low grade radioactive waste from effluent)

Why use biochar?

- As a filler it can (in the right amounts) enhance:
  - Compression strength
  - Flexural strength (MOR)
  - Curing
  - Electromagnetic Shielding
  - Fire Resistance
  - Insulation
  - Humidity Control
  - VOC Absorption (inc. possibly radon)
  - Sound Absorption

$7.20/lb!!
1:94 ratio

Or just be used as a dye!

Where is it happening?

- LOTS of commercial interest from around the globe
- Limited real world trials so far
  - Ithaka (Switzerland), The Farm (US),
- Research is increasing!
  - Canada, Italy, Japan, Korea, N.Z., Singapore, Switzerland, U.S.

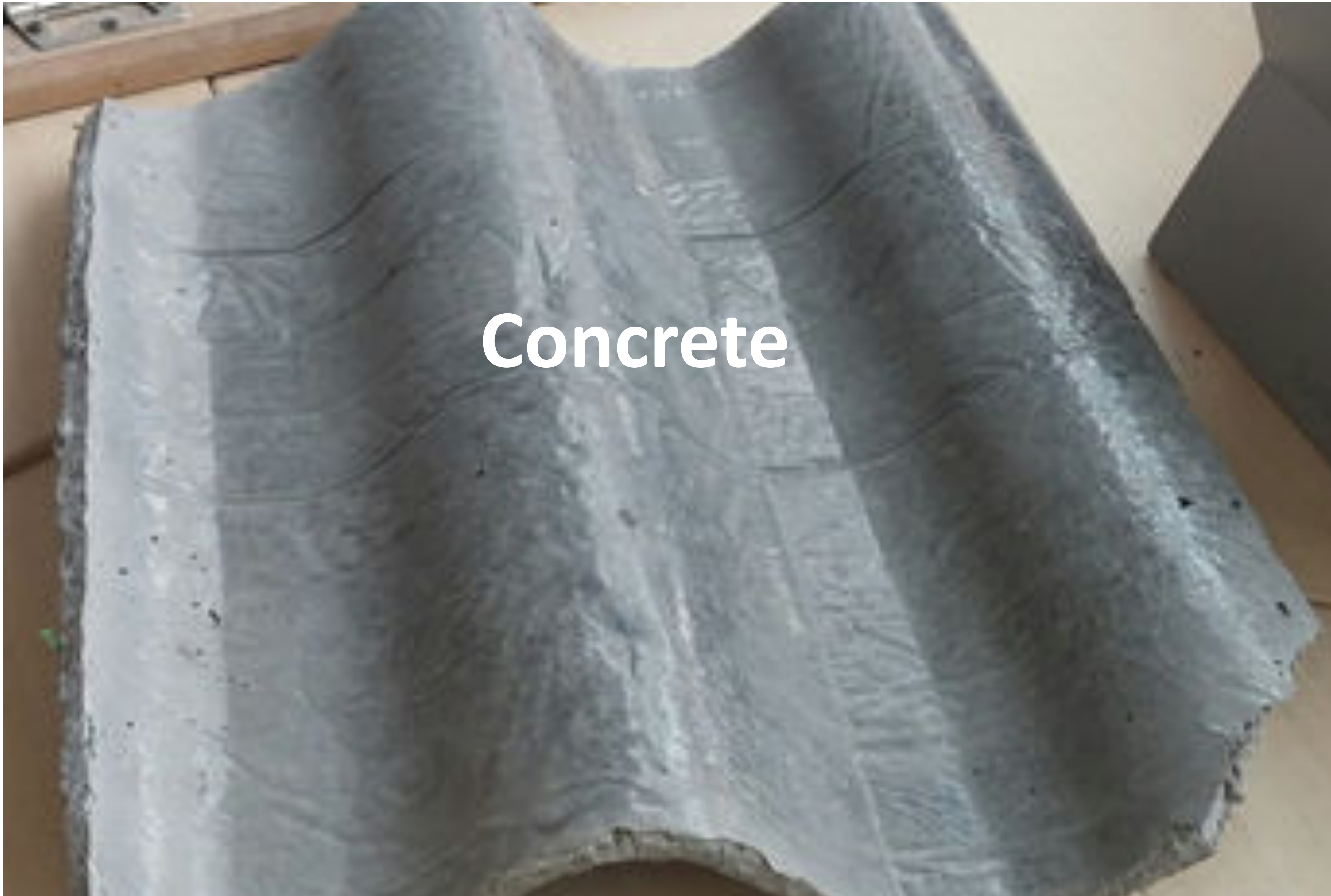
Which biochar properties matter?

Research is just beginning to show

BIOCHAR PROPERTIES		Soil			Bldg Mat		C
		Farm	Remed.	Storm	Conc.	Insul.	Seques
Chemical properties							
Prox	Ash (metals/minerals)	■			■	■	
	Carbon (fixed)	■			■	■	■
	Volatiles	■					
	Elemental comp: C_{org}, H, N, O	■					
	CEC (cation exchange capacity)	■					
	Degredation during storage	■					
	EC (electrical conductivity)	■					
	eH (electron activity)/REDOX	■					
	H:C ratio	■					■
	Liming	■					
	Macro/micro nutrients	■					
	PAH	■					
	ph	■			■	■	
	Reactivity						
	Self-heating						
	Structural composition						
Physical properties							
	Agglomeration potential				■	■	
	Bulk Density	■			■	■	
	Electromagnetic properties						
	Grindability/Hardness				■	■	
	Hydrophobicity	■			■	■	
	Mechanical Stability				■	■	
	Morphology				■	■	
	Particle size & distribution	■			■	■	
	Porosity: volume, pore size dist.	■			■	■	
	Surface area	■			■	■	
	Thermal Conductivity	■			■	■	
	Water Holding Capacity	■			■	■	

What does the research say

- Concrete
- Composites
- Asphalt
- Insulation


Concrete

What does the research say: Concrete

Restuccia et al 2016 (Italy)

Promising low cost carbon based materials to improve strength & toughness in cement composites

Project focus

Test mechanical properties of cement using 2 different chars:

- Coffee powder – unroasted discards 82.9%C, .3 Si
- Hazelnut shells (pellets) 97.9%C, .11 Si
- HHT: 800C
- Particle size: 10 – 15 um
- Used plasticizer to help with dispersion
- Tested at .5%, .8%, 1.0%

Results

- **All** char additives outperformed control bending strength, Compression & Fracture Energy
  - CP did better on Compression
  - HS did better on Flexural (MOR) and fracture energy
- HS' irregular morphology creates 'perfect bond with surrounding matrix'
- CP has higher Si which could work as an accelerator helping to speed up hydration process. Stabilized at 7 days!

What does the research say: Concrete

Restuccia et al 2017 (Italy)
Influence of filler size on mechanical properties of cement-based composites

Project focus

Evaluate mechanical properties when using course biochar particles as filler

- Hazelnut shell biochar, 97.9% C
- Tested at .5%, .8% and 1.0%,

Results

- Size and shape (morphology) matter!
- Flexural strength enhanced, fracture energy not enhanced after 28 days
- Dispersion is not homogeneous
- Lower additions of course particle size had higher positive impact on improving strength

What does the research say: Concrete

Choi et al 2012 (Korea)

Mechanical Properties of Mortar Containing Bio-Char From Pyrolysis

Project focus

Provide quantitative info on biochar so that it can be used as a C sequestration agent an/or as a self-curing agent.

- Hardwood biochar
- Tested at 5%, 10%, 15%, 20%

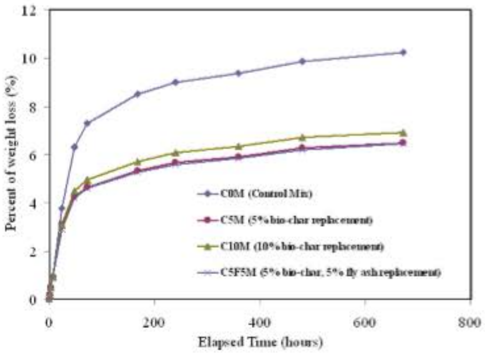


Fig. 3 Percentage of weight loss

Results

- All biochar admixtures had less weight loss due to moisture evaporation. Mortar mixes with char have better water retention. This may lead to improved strength. ‘In this way, biochar seems to play a role as a **self-curing agent**.’
- Workability of mortar decreases as biochar % increases
- 5 – 10% biochar replacement is similar to 20% replacement with fly ash
- Up to 5% biochar shows an increase in compression strength

What does the research say: Concrete

Khushnood et al 2018 ()

Carbonized nano/microparticles for enhanced mechanical properties & electromagnetic interference shielding of cementitious materials

Project focus

Test mechanical & SE properties of cement using 2 different chars:

- Peanut shell 93.8% C; Bulk density: 2.20 g/cm^3
- Hazelnut shells 87.7% C; Bulk density: 2.35 g/cm^3
- HHT: 850C
- Used plasticizer to help with dispersion
- Tested at .025%, .05% .08%, .2% .5%, 1.0%

Results

- **All** char additives outperformed flexural strength of control (2.96 MOR)
  - HS optimized at .25% (5.44 MOR)
  - PS optimized at .25% (5.43 MOR)
- Fine aggregates increase fracture toughness

Electromagnetic shielding

		Shielding efficiency improvement at 0.5%	
GHz	Devise	PS	HS
0.94	GSM mobiles	353%	335%
1.56	GPS	223%	214%
2.46	microwave	126%	122%
10.00	radio	83%	76%

What does the research say: Concrete

Tommaso et al 2016 (Switzerland)

NOx Adsorption, Fire Resistance and CO2Sequestration of High Performance, High Durability Concrete Containing Activated Carbon

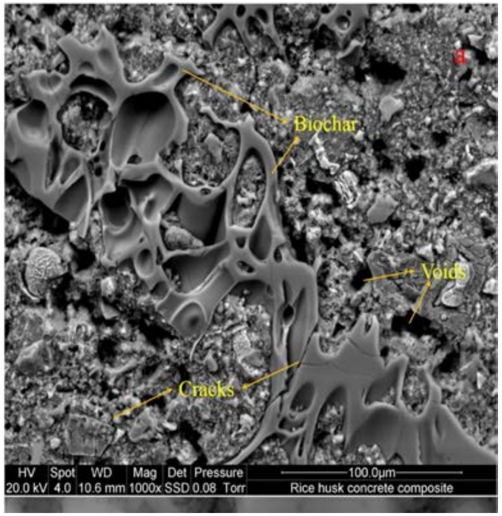
- Dramatically decreased levels of NO2 (66%)
- Very limited spalling during fire test

	Concrete requirements C50/60 XF4, XD3, XC4				
	Comparative mix			Reference mix	
Parameter	0.48% AC	1.06% AC	1.43% AC		Limits
Elastic Modulus (SIA 262/1 - G) [MPa]	41800	41300	41900	40400	--
Flexural Strength (SN EN 12390-5) [MPa]	5.0	5.4	5.4	4.9	--
Shrinkage (364-day) (SIA262/1-F) [με]	419	452	458	423	--
Freeze - Thaw Resistance (SIA262/1-C) [g/m^2]	200	70	80	40	$\leq$ 200
Resistance to Chlorides Penetration (SIA 262/1 - B) [m^2/s]	$2.3 \cdot 10^{-12}$	$2.2 \cdot 10^{-12}$	$1.7 \cdot 10^{-12}$	$3 \cdot 10^{-12}$	$\leq 10 \cdot 10^{-12}$
Absorption by Capillarity (SIA 262/1-A) [$g/(m^2 \cdot h)$]	6.8	4.5	4.2	5.7	$\leq$ 10
Resistance to sulphates (SIA 262/1-D) [‰]	0.36	0.31	0.46	0.32	$\leq$ 1.2
7-day Compressive Strength (SN EN 12390-3) – [MPa]	52.3	51.3	53.0	50.0	--
28-day Compressive Strength (SN EN 12390-3) – [MPa]	71.8	65.8	61.8	65.3	$\geq$ 64
Coefficient of carbonation (SIA 262/1-I) - [mm/√year]	--	1.38	--	--	< 4.5

Control

What does the research say: Concrete

Akhtar et al 2018 (New Zealand)
Novel biochar-concrete composites: Manufacturing, characterization and evaluation of the mechanical properties



Project focus

- Study the effect of 3 different biochars as additive in concrete on its strength properties & determine optimal usage in conventional concrete applications
- Biochars used: poultry litter (PL), pulp & paper (PP), rice husk (RH)
- Concentrations used: .1%, .25%, .5%, .75%, 1.0%

Results

- PP & RH at 0.1% of total volume most suitable replacement binder with respect to mechanical strength.
- PL & PP improved water absorption
- PL & RH exhibited water absorption equivalent to control specimens

Impact: Concrete

Concrete

- 25 billion tons/year
- 1% biochar = 250 million tons/year
- With C content of 82% - 98%
  - 205Mt – 245Mt carbon sequestration
  - 738 – 882Mt CO2e

Composites

Composite

- two or more different materials combined together to create a superior and/or unique material.

Bio Composite

Natural fibers including wood or non-wood (e.g. grasses) blended with a matrix (binder) made from either renewable or non-renewable sources.

Examples

Concrete, Asphalt, Ceramics, Plastics,

What does the research say: Composites

DeVallance et al 2016 (USA)

Investigation of hardwood biochar as a replacement for wood flour in wood-polypropylene composites

Project focus

Combine BC with wood and plastic to make alternative composites to traditional wood-plastic composites and test flexural & tensile strength, water absorption, thermal & particle distribution testing

- Tested biochar rates at 5%, 15%, 25%, 40% by wt

Results

- All biochar rates increased flexural strength by 20% or more
- Tensile strength was highest with 5% biochar
- Tensile elasticity was highest with 25% and 40% biochar
- Water absorption and swell decreased
- Biochar additions showed improved thermal properties

WPC used in building & construction, automotive & consumer products

What does the research say: Composites

Bowlby et al 2018 (Canada)
Flexural strength behavior in pultruded GFRP composites reinforced with high specific-surface-area biochar particles synthesized via microwave pyrolysis

Project focus

Assess viability of MW pyrolysis to synthesize high surface area biochar from woody and ag biomass
Use biochar as reinforcing filler in pultruded glass fiber reinforced polymers to enhance flexural strength

- Biochars tested: maple, spruce, switchgrass. Avg temp 700C

Results

- All biochar rates increased flexural strength at both 5% & 10%. Nearly double at 10%
- Higher porosity enhanced amount of molten polymer infiltration
- Enhanced compressive strength due to inherent hardness of biochar
- Hardness increased 4x but stiffness only by 45%
- s/w (spruce) performed best – small pores but more of them, highest surface area


Asphalt

What does the research say: Asphalt

Zhao et al 2014 (USA)

Lab investigation of Biochar-modified Asphalt Mixture

Project focus

Evaluate biochar impact on hot-mix asphalt properties as compared to carbon black and carbon fiber.

- Feedstock: Switchgrass; HHT 400C
- Up to 10% by wt of asphalt
- Particle size ,75um

Results

- Bending strength decreases in temps ranging from 300C – 500C, then increases above 500C
- Biochar more effective asphalt modifier for reducing temp susceptibility of asphalt binder.
- Biochar showed highest rutting resistance

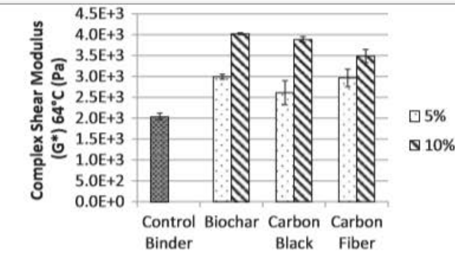


FIGURE 5 G* results at high service temperature (64°C).

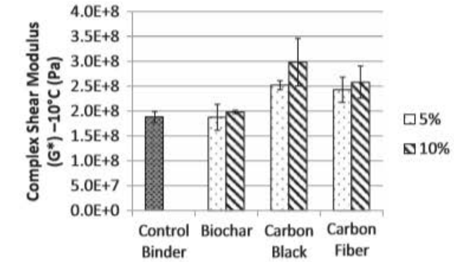


FIGURE 6 G* results at low service temperature (−10°C).

Transportation Research Record 2445

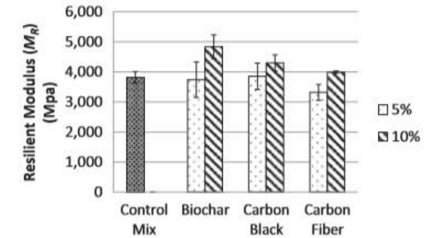


FIGURE 7 M_R results at 25°C.

What does the research say: Asphalt

Jeffry et al 2018 (Malaysia, Canada)
Effects of nanocharcoal coconut-shell ash on physical & rheological properties of bitumen

Project focus
Identify modifier to bitumen that improves performance and longevity of asphalt.

- Feedstock: Coconut shell; HHT 400C
- Up to 1.5%, 3%, 4.5%, 6%, 7.5% by wt of asphalt
- Particle size average 57.7 nm

Results

- Nano size increases surface area and improved bonding
- Up to 6% decreased penetration (i.e. increased hardness)
- Up to 6% increased softening point/temperature

Impact: Asphalt

Asphalt

- 1,600 million metric tons/year*
- 10% biochar = 160 million metric tons/yr
- With C content of 56% (typical for switchgrass @ 400C)
  - 89 mt C sequestration
  - 322 mt CO2e

http://www.eapa.org/userfiles/2/Publications/GL101-2nd-Edition.pdf

Insulation

Super Graphite EPS Foam Board

What does the research say: Insulation

Lee et al 2018 (Korea)

Experimental research on the indoor environment control of natural insulation materials: carbonized rice hulls and straw bales

Project focus

Reduce embodied CO2 emissions and energy consumption, assess cost effectiveness, performance on thermal insulation, humidity control and indoor air quality

- Carbonized rice hulls; low density -> high breathability, low water retention 2.5x weight

Results

- Humidity control generally 40 – 63% (within comfort zone) even during monsoon season
- Carbonized hulls and straw bale have similar insulation capacities
- Straw bale, under high heat & humity can lead to unhealthy mold unless carefully waterproofed; charred hulls does not have this problem.

What does the research say: Insulation

Matsumoto et al 2017 (Japan)
Effects of moisture controlled charcoal on indoor thermal and air environments (conference abstract only)

Project focus

- Improve thermal comfort and save energy in buildings
- Clarify effect of moisture control using charcoal on indoor thermal and air environment + removal of VOCs
- Placed 4 bags of charcoal on floor in attic & compared to similar room without charcoal in attic

Results

- 'significant' effect on moisture control in hot & humid weather
- 'remarkable' performance of VOC removal (formaldehyde)

What does the research say: Insulation

Yardanova 2016 (USA – doctoral thesis)

Corn stover biochar in gypsum board: Empirical analysis of thermal conductivity and flexural strength(abstract only)

Project focus

- Improve the performance of gypsum board by studying the thermal conductivity, density, and flexural strength of a biochar-gypsum composite.

Results

- inclusion of biochar in gypsum decreased the thermal conductivity, flexural strength, and density of the composite.
- Results from the flexural strength test indicated that including biochar within certain range produced a composite meeting, and in some case exceeding, the current ASTM C 1396 standard


QUESTIONS?
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