Biochar composites for sustainable thermal packaging applications

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Background

- Thermal packaging is used to transport temperature-sensitive products including vaccines, high-value food products, etc.
- The most common conventional material is expanded polystyrene (EPS), produced at very large scale and low cost but with significant environmental impacts.
- Objective: develop sustainable thermal packaging materials with reduced embodied carbon and end-of-life impacts, through use of biochar and waste biomass materials.

Materials

- Biochar composite materials evaluated vs. “Styrofoam”, expanded polystyrene (EPS)
- Biochar A: derived from woody biomass, nominally spherical particles
- Biochar B: derived from agricultural residue, nominally rod-shaped particles
- Organic binder derived from macroalgae
- Composites blended manually and formed into panels with silicone molds

Biochar comparison

Parameter		Biochar A	Biochar B
Bulk density [kg/m^3]		308.8	113.6
Organic carbon [% total dry mass]		87.9	44.4
H:C [molar ratio]		0.25	0.70
Surface area via butane activity [m^2/g]		322	286
Particle size (%)	< 0.5 mm	100.0	10.2
	0.5 – 1 mm	0	46.2
	1 – 2 mm	0	38.4
	2 – 4 mm	0	5.2

EPS

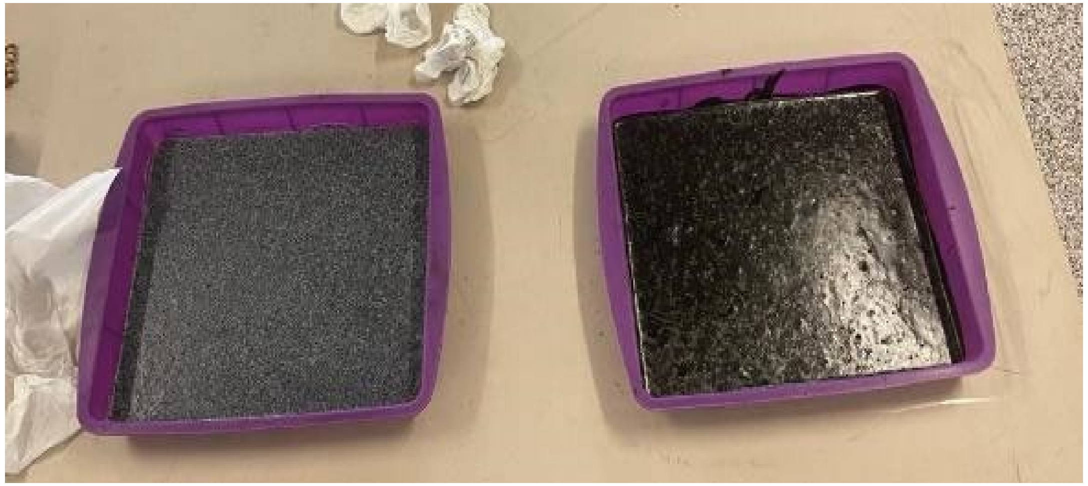
Binder only

Binder + 50% Biochar A

Binder + 33% Biochar B

Biochar composite panel fabrication and drying

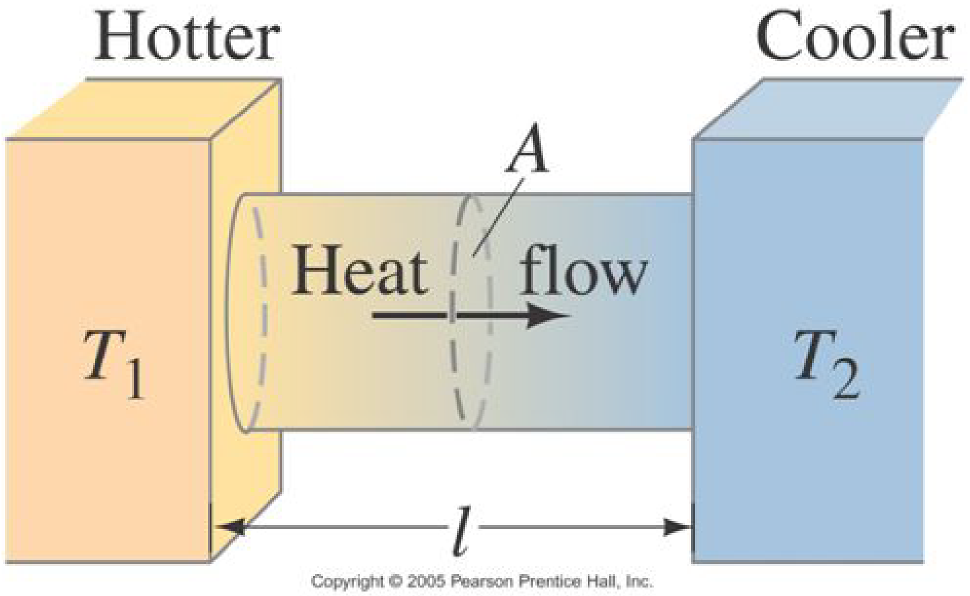
Fabrication of panels



Freeze Dryer (Harvest-right™)

Oven replaced by Freeze Dryer

Thermal conductivity, *k*



$T_1 > T_2$

- Consider a uniform cylinder conductor of length l with temperature T_1 at one end and T_2 at the other end as shown in figure above.
- The heat flows to the right because T_1 is greater than T_2.

Ref: https://www.techglads.com/cse/sem1/thermal-conductivity/

Thermal conductivity calculation

$$\text{Thermal conductivity, } k\ [W/(m*K)] = \frac{\text{(heat flow) (thickness of panel)}}{\text{(area)(change in temperature)}} = \frac{QL}{A\Delta T}$$

where:

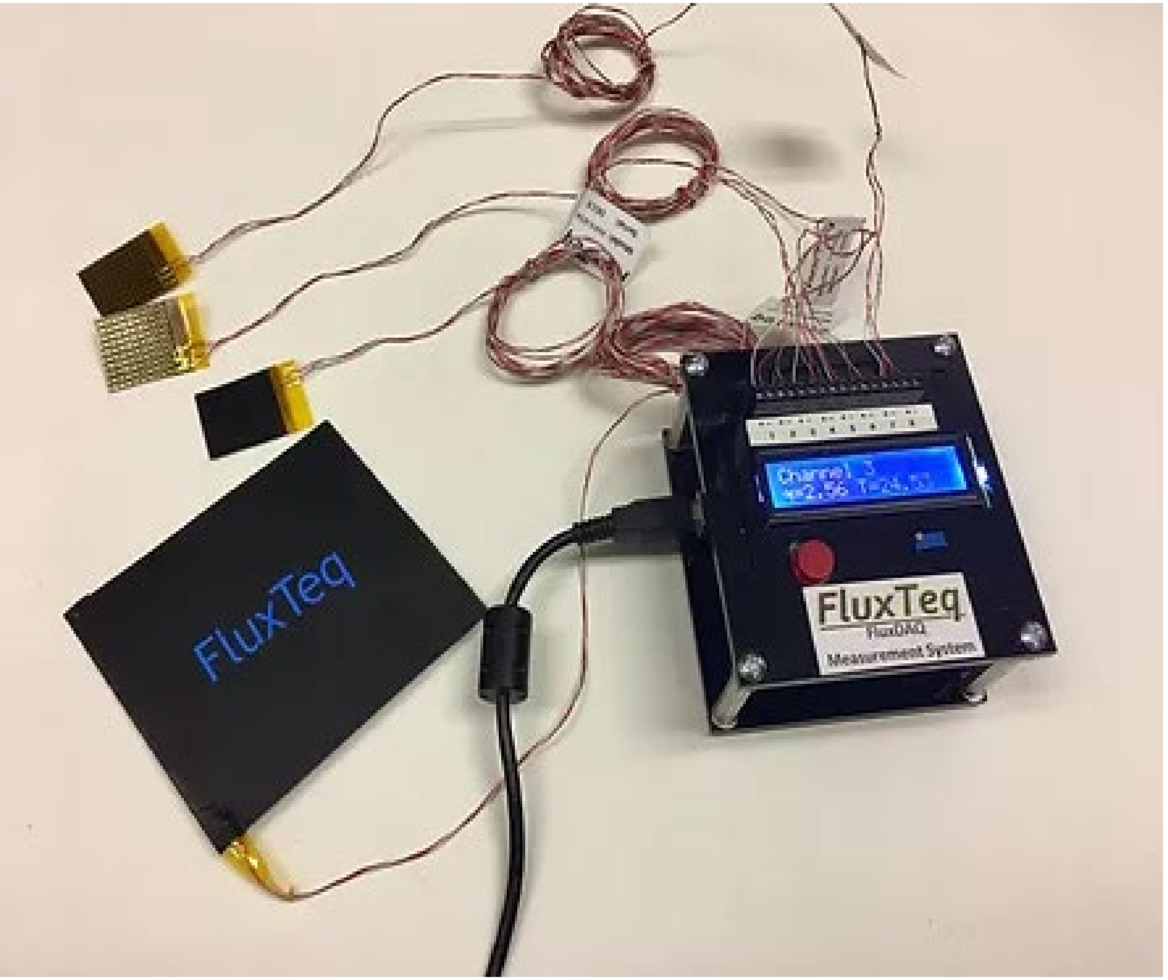
k = thermal conductivity [W/(m K)]

Q = heat transfer through the material [J/s or W]

L = thickness of panel [m]

A = area of the body [m^2]

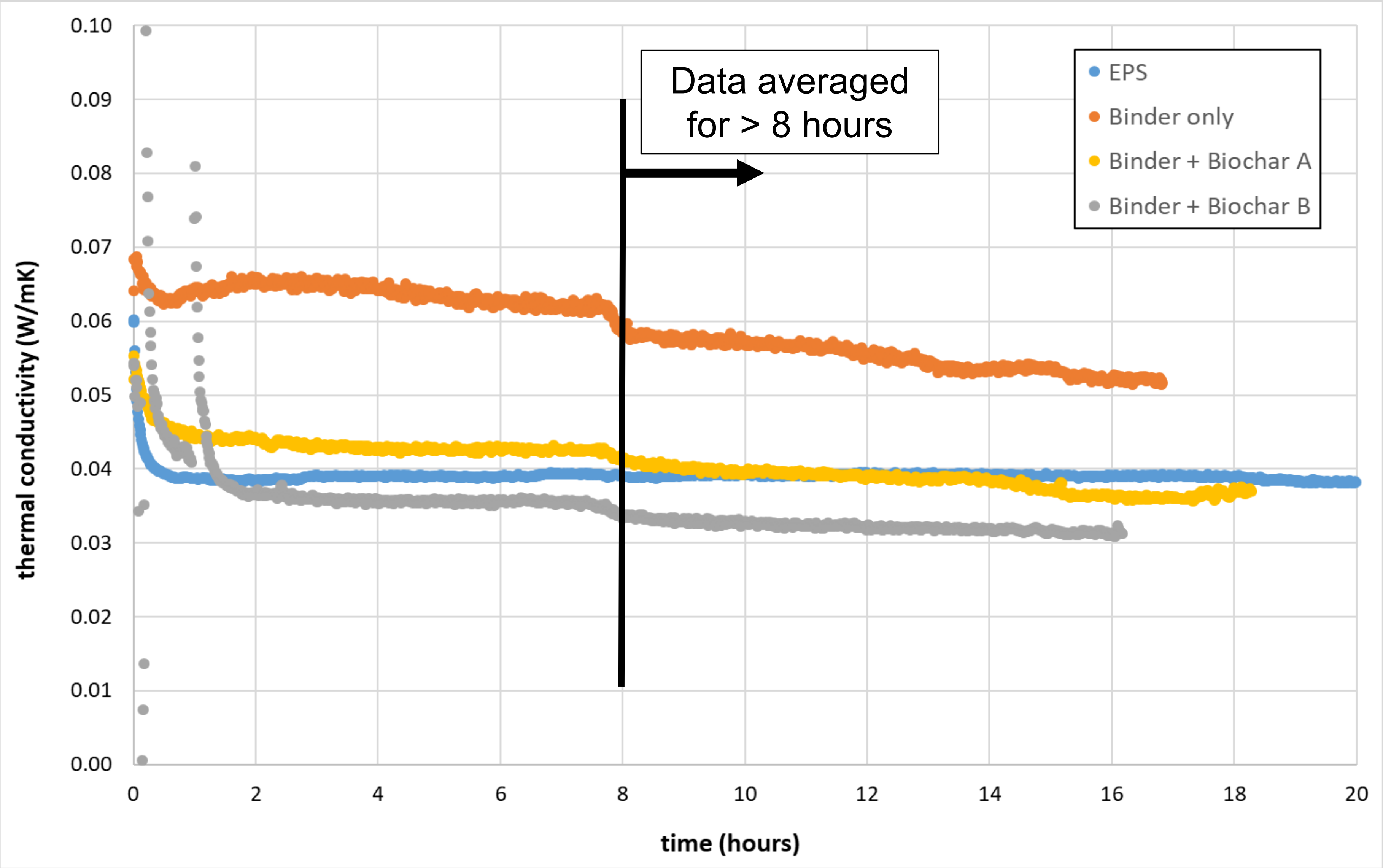
ΔT = temperature difference [K]



Heat flux and temperature measurement devices from FluxTeq

Complete system set-up (Ice maker, FluxTeq, Cooler, Simulation)

Time-varying FluxTeq data



Computed R-value & thermal conductivity

Thermal resistance (R-value)	EPS	Binder only	Binder + 50% Biochar A	Binder + 33% Biochar B
[(K · m ^{2})/W]	3.50	0.49	0.94	1.03
standard deviation (N = 3)	0.09	0.04	0.07	1.75

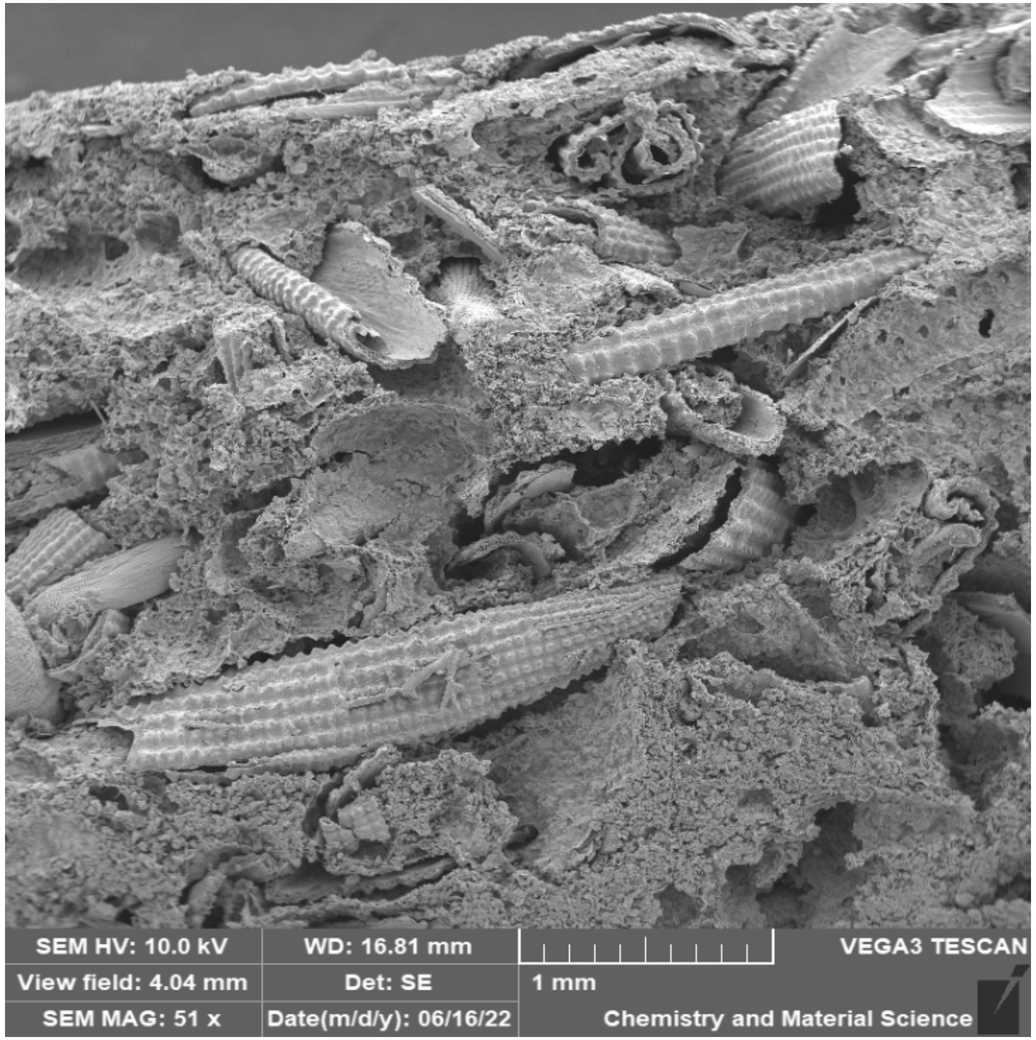
Thermal conductivity (k)	EPS	Binder only	Binder + 50% Biochar A	Binder + 33% Biochar B
[W/(m K)]	0.039	0.059	0.041	0.035
standard deviation (N = 3)	0.001	0.005	0.003	0.006

Thickness and density effects

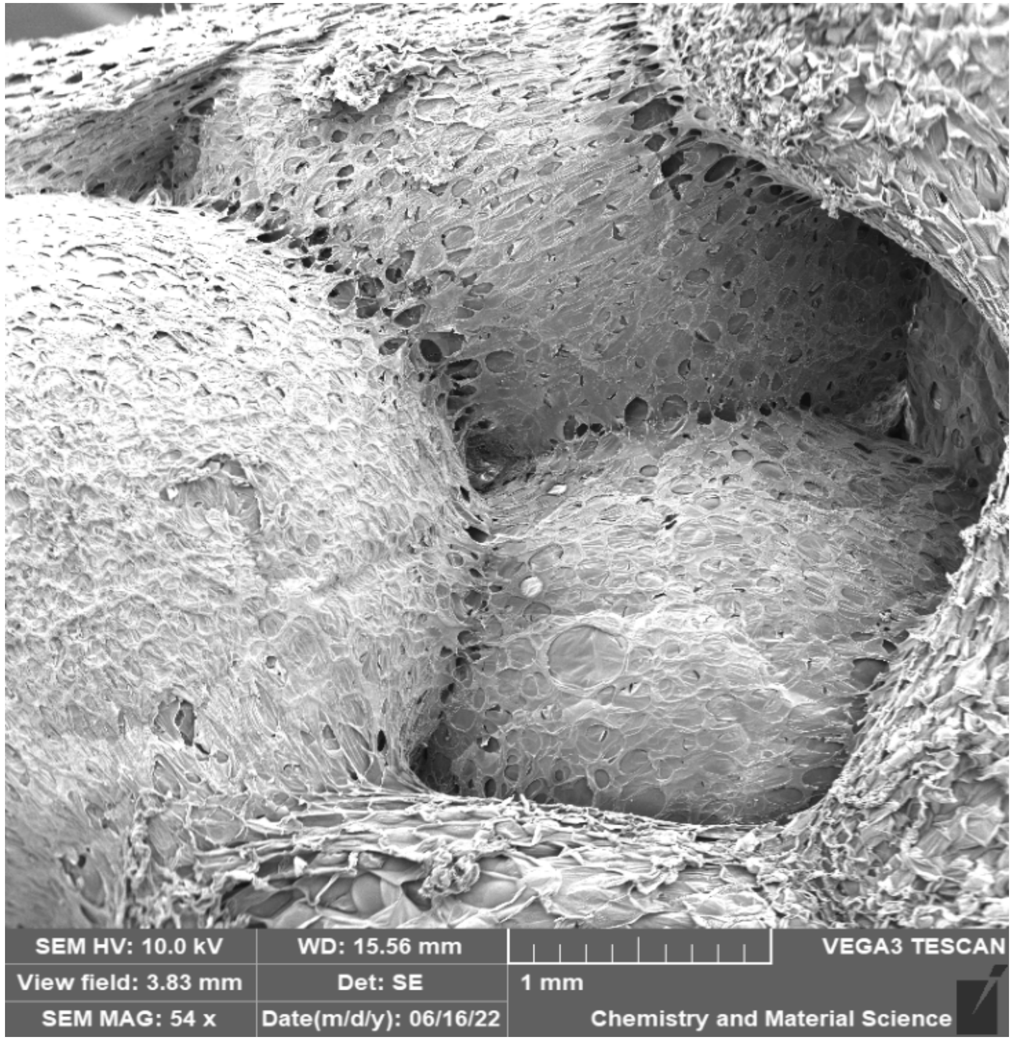
Parameter	EPS	Binder only	Binder + 50% Biochar A	Binder + 33% Biochar B
Thickness [mm]	25.4	5.1	6.7	6.2
R-value [(K · m ^{2})/W]	3.50	0.49	0.94	1.03
k [W/(m K)]	0.039	0.059	0.041	0.035
Density [g/cm^3]	0.012	0.465	0.360	0.295

- *Biochar composites achieve thermal conductivity comparable to EPS, but with 25 to 30 times greater density.*

Scanning electron microscopy (SEM) @ ~50X

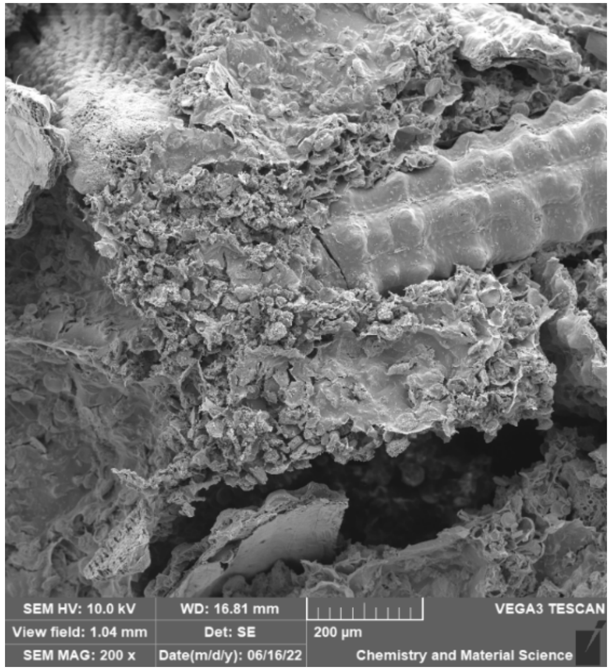


Binder + Biochar B @51x

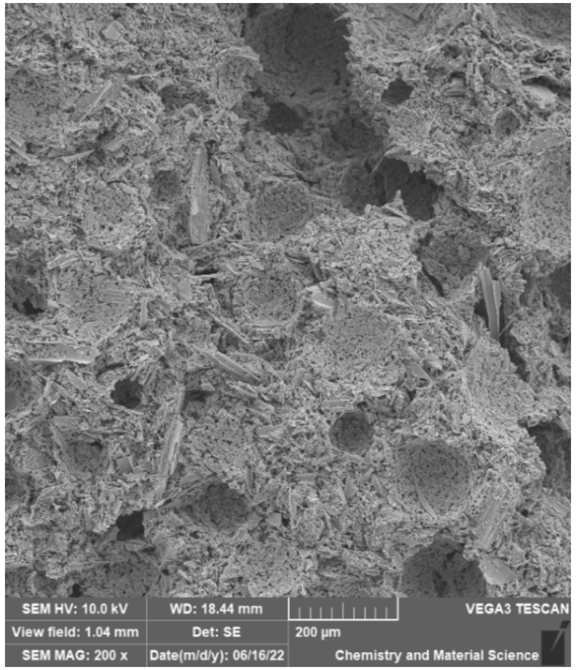


EPS @54x

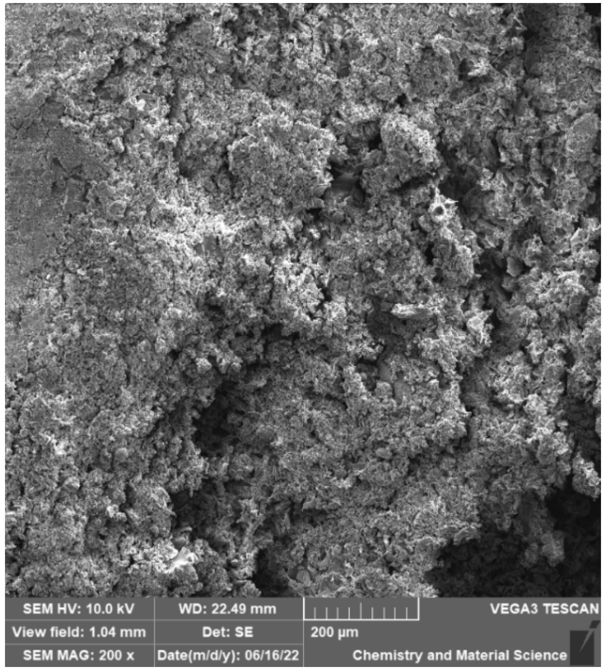
SEM @ 200X



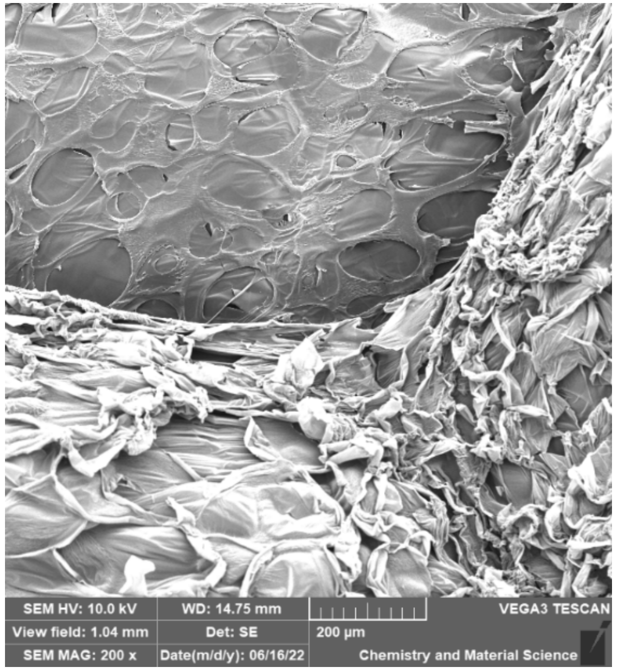
Binder + Biochar B



Binder + Biochar A

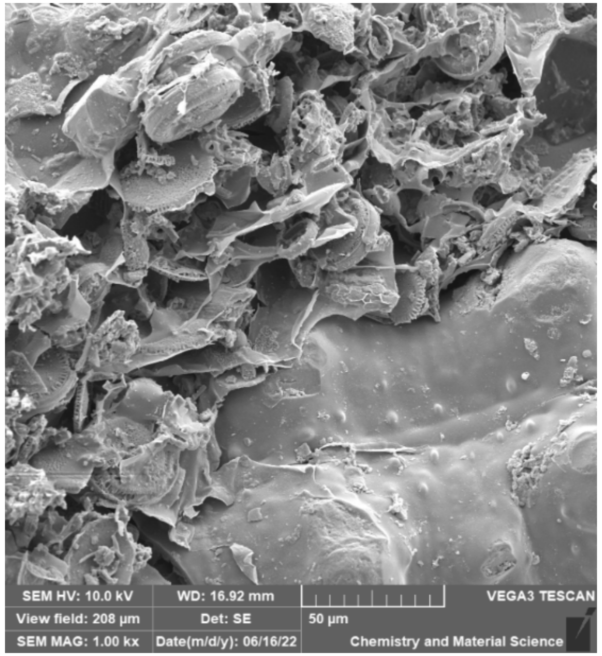


Binder only

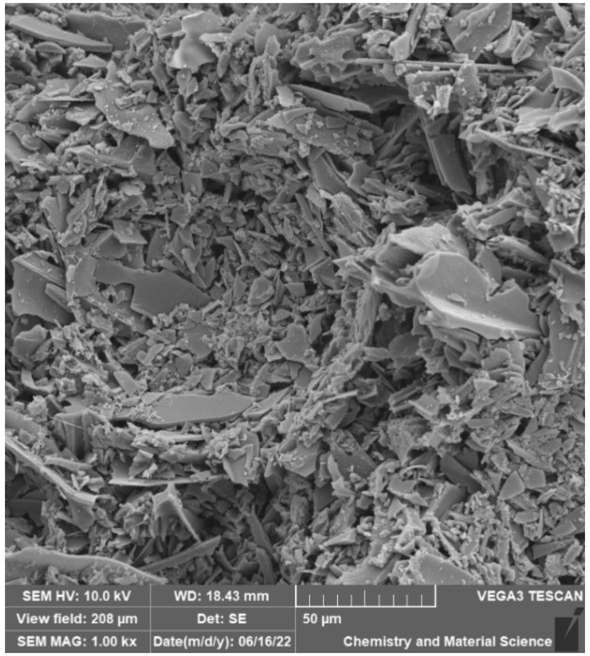


EPS

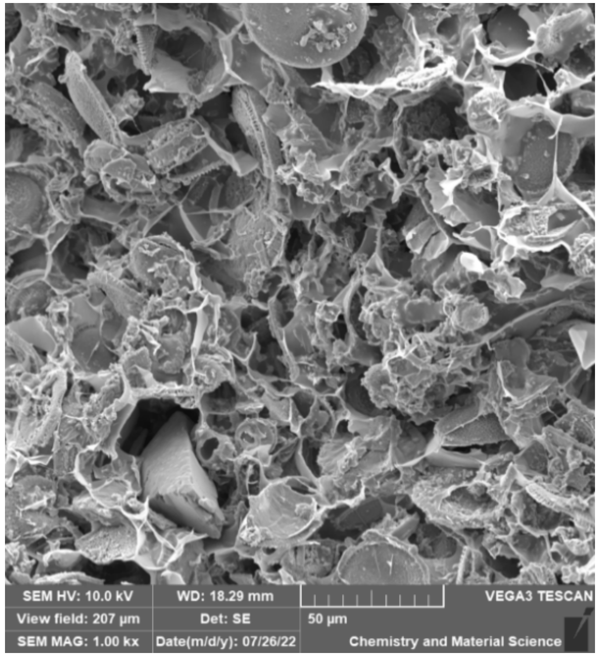
SEM @ 1000X



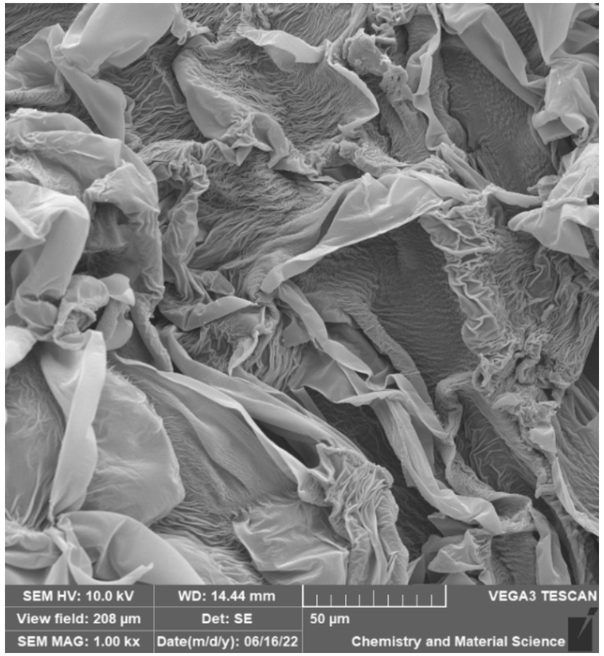
Binder + Biochar B



Binder + Biochar A



Binder only



EPS

Conclusions and future work

- Sustainable thermal packaging materials were developed by combining biochar with an organic binder.
- Composites based on two types of biochar with widely varying properties yielded thermal conductivities comparable to expanded polystyrene, with densities 25 to 30 times greater than EPS.
- Scanning electron microscopy images highlight morphological features that may help explain the low thermal conductivity values achieved.
- More research is needed to understand the trade-offs among thermal conductivity, density and mechanical properties.
- Biochar composites show promise as a pathway to displacing EPS, but much lower cost targets must be met for full-scale production.

Thank you!

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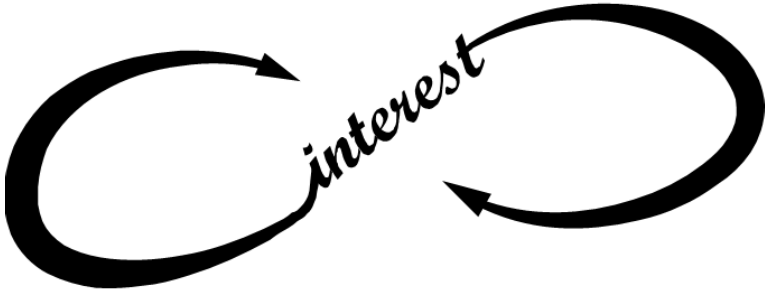

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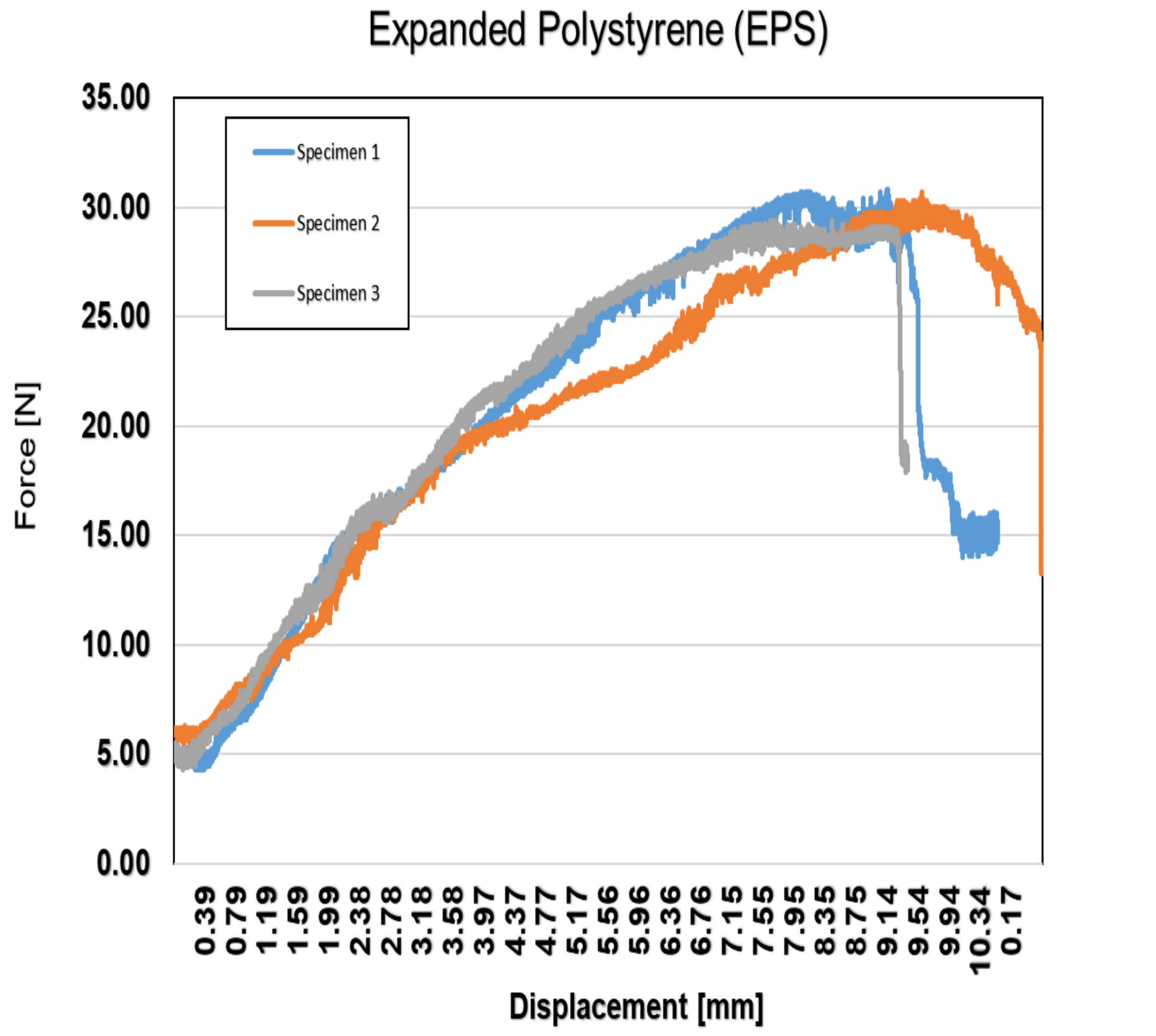
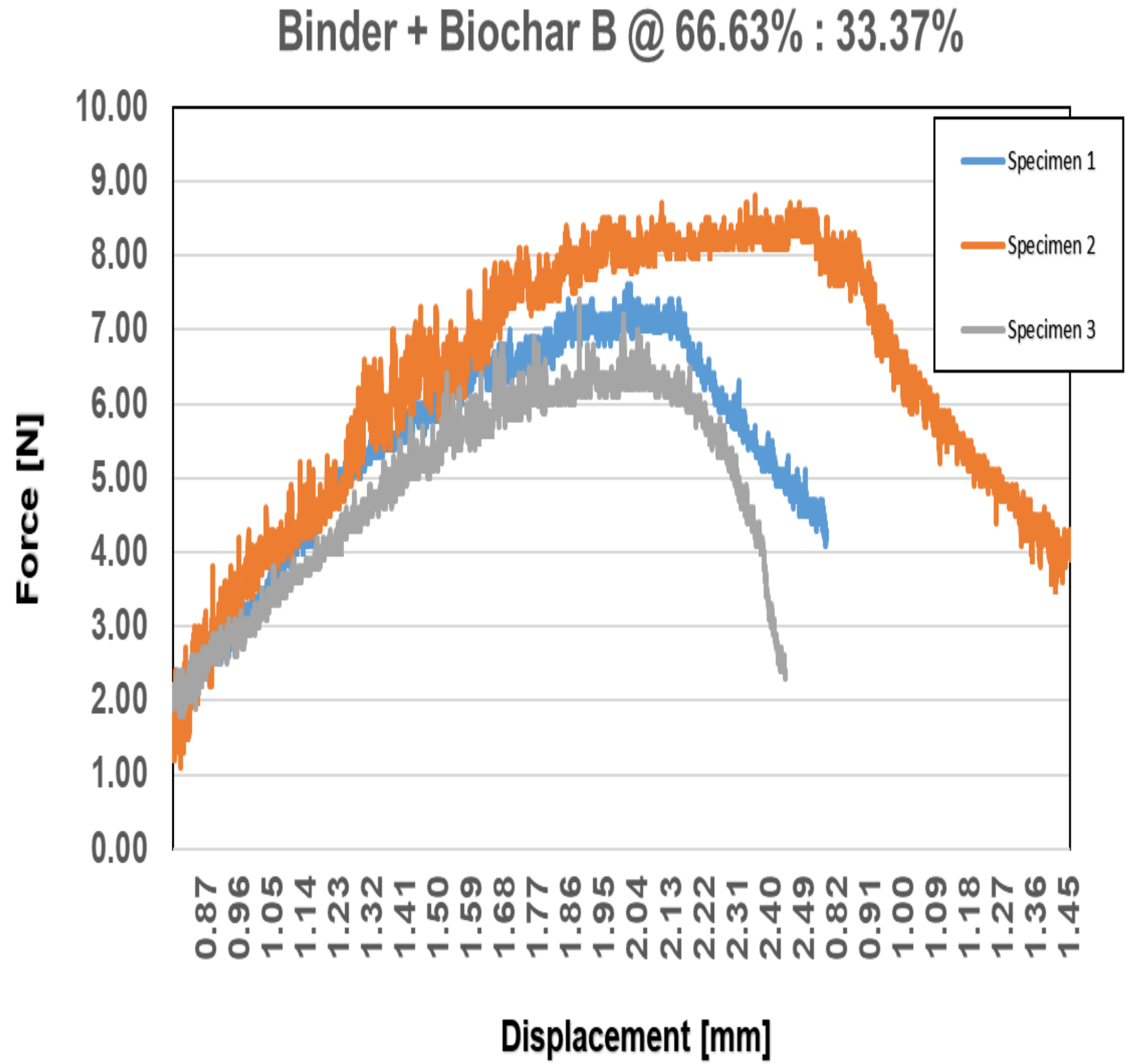
3 point bend test





3 point bend test