DEVELOPMENT OF LOW-CARBON CONCRETE MATERIALS INFUSED WITH BIOCHAR FOR BRIDGE APPLICATIONS

Quarterly Progress Report
For the period ending March 31, 2024

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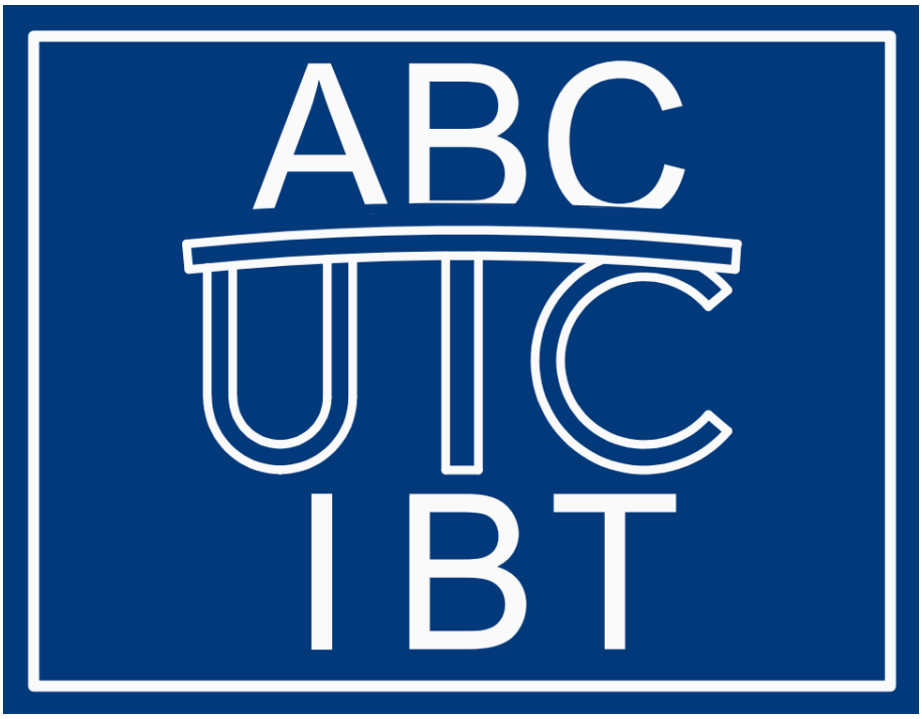

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1. Background and Introduction

Concrete's high carbon footprint is an ongoing concern for infrastructure sustainability and environmental stewardship. A primary strategy in the quest for low-carbon concrete is to replace a portion of the portland cement with pozzolanic wastes generated by other industrial or societal activities. Biochar is a product of biowaste combustion. Some sources are pozzolanically active and can therefore enhance concrete's later-age mechanical and durability properties of concrete. In addition, biochar efficiently absorbs atmospheric CO_2, a first step in CO_2 sequestration in concrete by carbonate mineralization. But despite this potential *multifunctional* nature of biochar, its assured use in concrete for bridge elements will not be realized until its influences on fresh-state workability and early strength development are better understood and controlled. New materials enabled by this research will significantly decrease anthropogenic GHGs, increase the resilience and sustainability of civilian infrastructure, and provide a sink for biowaste materials that otherwise would be deposited in landfills.

2. Problem Statement

The concrete industry faces urgent calls from world governments and the public to reduce its carbon footprint, which contributes about 8 % of anthropogenic greenhouse gas emissions annually [Habert 2013]. With the prospect of CO_2 taxation that could range from $2 USD to $168 USD per equivalent short ton of CO_2 produced [World Bank 2016], concrete must evolve to a low-carbon material to remain economically viable in the latter half of the 21st century [Biernacki 2017].

Two main strategies have emerged toward low-carbon concrete. One of these is a "back-end" loading of concrete with CO_2, either absorbed passively from the environment during its service live or actively injected from stored CO_2. Either way, the absorbed CO_2 is eventually locked chemically within the concrete in the form of carbonate minerals such as calcite, or magnesite, or hydrotalcite. The second strategy focuses on the "front end" of concrete production by replacing as portion of portland cement with pozzolanic waste material from other industrial or societal activities.

Biochar additions bridge both of these approaches. It is a waste product of combustion of organic material (wood, rice husks, corn husks, manure, or other agricultural waste products) [Spokas 2020]. Depending on the source [Tan 2021; Maljaee 2021; Gupta 2017], biochar is highly porous, with CO_2-accessible surface areas of ~300 m^2/g, porosities up to 50 %, and pore sizes down to several nanometers. With high ash content biochar is pozzolanically active. It also efficiently absorbs CO_2 and thereby promotes carbonate mineralization with dissolved alkali earths such as calcium. In cement, milled fast-pyrolysis char has been used at up to 32 % replacement by mass with improved compressive strengths due to its role as an internal curing source and nucleating agent for calcium silicate hydrate gel (C-S-H) [Tan 2021; Pecha 2022].

But despite this potential *multifunctional* nature of biochar as a concrete additive, the assured use of biochar-infused concrete for bridge elements will not be realized until its influences on fresh-state workability and early strength development are better understood and controlled. New materials enabled by this research will significantly decrease anthropogenic GHGs, increase the resilience and sustainability of civilian infrastructure, and provide a sink for biowaste materials that otherwise would be deposited in landfills.

3. Objectives and Research Approach

The overarching research objective is to develop low-carbon concrete materials infused with biochar that potentially can be implemented in bridge construction and repair. The primary knowledge gaps toward that end are the early-age structure-processing-property relationships. Quantifying these relationships will enable biochar-infused concrete to be used reliably and at higher volume fractions of replacement for portland cement. Within that objective, our specific goal in this project is to map the relationships among biochar dosage and properties (ash content, fineness, and porosity) to fresh flow properties (yield stress, shear-dependent viscosity, and thixotropy) and early-age mechanical properties and microstructure.

4. Description of Research Project Tasks

The following is a description of tasks carried out to date.

Task 1 – Screen and characterize biochar sources

No more than three biochar candidates will be chosen based on ash content, composition and alkaline reaction rates (for pozzolanic potential), porosity (for internal curing potential), specific surface area (for carbonate adsorption, water demand, and superplasticizer dosage requirements), and density. With the target of leveraging pozzolanic activity for later-age strength and durability, the biochars will all be chosen to have a high silica content. Among the high-silica sources we will choose candidates to span the practical range of specific surface areas and densities.

Based on that initial screening for materials selection, the chosen biochars will be thoroughly characterized for their true density, particle size distribution, chemical composition, crystalline and amorphous content, and hydraulic activity in alkaline solutions:

- X-ray fluorescence (XRF) spectroscopy will be used to obtain elemental composition on an equivalent oxide basis;
- Microthermogravimetric analysis (TGA) will be used to determine not only the loss on ignition (LOI), but also to identify the presence of residual hydroxides or carbonates;
- Isothermal microcalorimetry (IC) will be used to characterize the pozzolanic potential of each biochar material in an alkaline solution to simulate conditions in a concrete binder.
- Nitrogen adsorption BET isotherms will be used to measure specific surface area;
- Pycnometry will be used to determine true density and water absorption; and
- Scanning electron microscopy (SEM) will be used to visualize particle morphology

Description of work performed up to this period

Q1: Two different biochar materials have been received from Glanris LLC. One of them is a sawdust-derived biochar that is low in SiO_2, and the other is a rice hull-derived biochar that is higher in SiO_2. The materials have been ground by ball milling and their physical properties have been characterized both in the as-received and ground conditions. Properties measured are water absorption capacity, morphology as observed by scanning electron microscopy,

thermogravimetric data, and particle size distribution as measured by laser diffraction in a dilute ethanol suspension.

Task 2 – Map the rheological properties of pastes and mortars

Each of the selected biochars will be integrated with a Type I/II portland cement to make a range of pastes and mortars that will be the subject of a factorial design experiment that will determine the influence on fresh rheological properties of mixture proportions as well as any interactions among the mixture components.

Description of work performed up to this period

No work performed on Task 2 in this period.

Task 3- Determine biochar influence on early-age hydration, carbonation, and mechanical properties

We will use a subset of the combinations described above of mixture formulations to determine the influence of different biochars on overall reaction rates, setting times, microstructure evolution, and 3-d and 7-d mechanical properties.

Description of work performed up to this period

No work performed on Task 3 in this period.

5. Expected Results and Specific Deliverables

Research Outputs:

- *Rheological properties*: flow curves (shear stress versus strain rate), viscosity, yield stress, and storage modulus of fresh material.
- *Hydration properties:* net hydration rate as a function of time, phase change with time
- *Mechanical properties:* initial and final setting times, 3-d and 7-d properties such as nanomechanical characteristics of cured constituents and interphase, and strength (compressive or flexural)
- *Microstructure characteristics:* 3-d and 7-d SEM and X-ray CT imaging
- *Response surfaces:* how each of these properties correlates with mixture characteristics (biochar content and source, w/s volume ratio, and superplasticizer dosage), including interactions among these mixture characteristics.

- *Later-age strength development.* A simple model based on regression of Powers gel-space ratio relation to compressive strength, where the model parameters dependences on mixture proportions are clarified.

Deliverables:

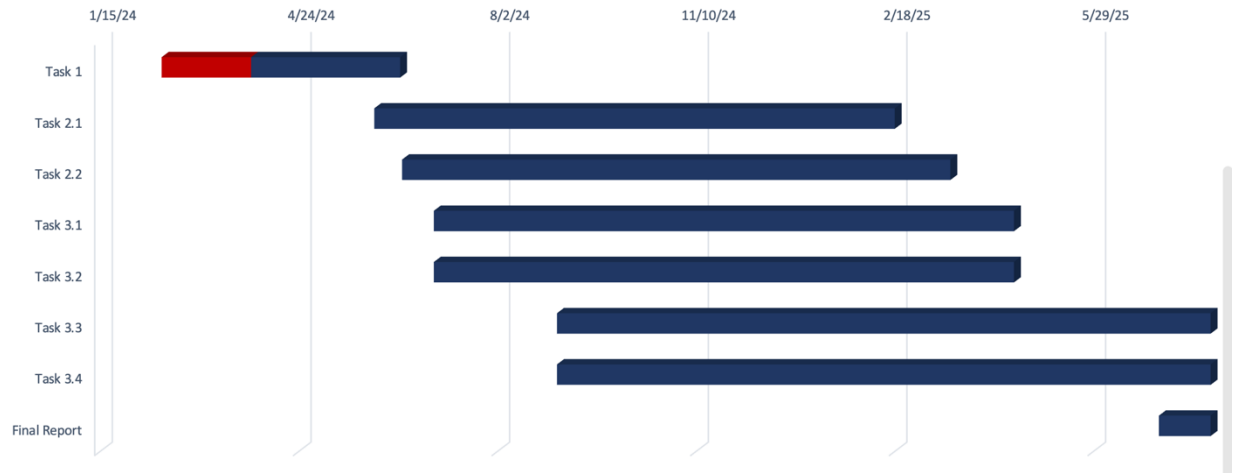
- *Structure-property-processing relationship data*
- *One submitted peer-reviewed journal paper on research outcomes*
- *One domestic conference presentation on research outcomes*
- *Final project report*

6. Schedule

Progress of tasks in this project is shown in the table below.

(**SHOW SCHEDULE OF WORK PERFORMED AND TO BE PERFORMED ON A BAR CHART, SAMPLE CHART SHOWN BELOW**)

Item	% Completed
Task 1	30 %
Task 2	0 %
Task 3	0 %



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