Cellulose Nanocrystals as a Value-Based Additive for Low Carbon Footprint Concrete with Limestone

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Cellulose nanocrystals (CNCs) can be produced from woody biomass gathered from activities such as thin-from-below prescriptions for sustainable forest management, helping to reduce hazardous fuels and improve forest health. This research was aimed at evaluating CNCs as a value-based additive that can aid in concrete mixture modifications to reduce concrete's carbon footprint.

What are CNCs?

CNCs are cellulose-based nano-sized particles (3-20 nm wide and 50-500 nm long) that are much smaller than conventional cellulose fibers used in concrete, and even smaller than cement particles themselves. Figure 1 shows a transmission electron microscope (TEM) image of CNC produced from the CNC pilot plant located at the US Forest Service, Forest Products Laboratory. A wide range of applications are being investigated to utilize CNCs.

Figure 1. Bridge constructed using CNCs from woody biomass, Yreka, CA.

CNCs as an additive for low carbon footprint concrete with limestone (LS)

Dosages of CNCs (between 0 and 1%) were added to ordinary portland cement - limestone (OPC-LS) mixtures with different LS contents (up to 30% by mass) to study CNCs' impact on OPC's degree of hydration, porosity, flexural strength, and electrical resistivity. The major findings were:

- The addition of up to 0.5% CNCs to OPC-LS mixtures resulted in an increased degree of hydration of binder (OPC+LS) at all ages (7 & 28 days).
- The early-age increase in degree of hydration of binder was attributed to the combined effect of LS and CNCs. The increased later-age degree of hydration was due to CNCs.
- The increased degree of hydration resulted in a decrease in pore connectivity and an increase in bulk resistivity (indication of improved durability).
- Mixture with 20% LS and 0.2% CNC had similar bulk resistivity to OPC mixtures, resulting in ~19% lower GHG emissions (Figure 2)
- CNC addition did not have a significant impact on the overall porosity (volume fraction of voids) and flexural strength of the OPC-LS mixtures.

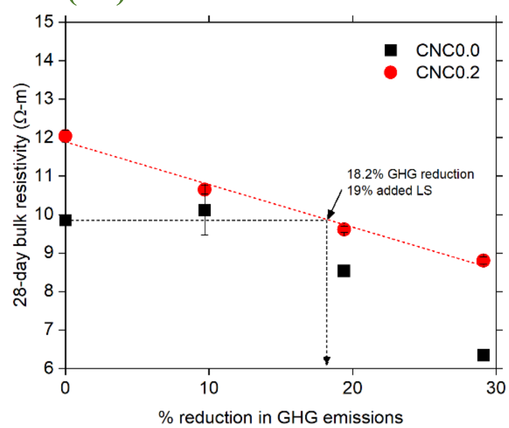

Figure 2. Y-axis shows 28-day bulk resistivity for OPC-LS mixtures & X-axis shows % reduction in GHG emissions from the use of limestone. The plot shows that with the use of CNC at 0.2% dosage, about 18% reduction GHG emissions can be achieved from using 19% limestone to have same bulk resistivity as the plain system without CNC.

Figure 3. Field placement of mixtures 1) OPC (top slab in the picture) 2) OPC+CNC 3) PLC+CNC (bottom slab in the picture).

Field demonstration of CNCs use in concrete

Successful use of CNCs and portland-limestone cement (PLC) was demonstrated in field trials in California at the UC Davis Pavement Research Center. With the addition of CNCs, there was no significant difference in fresh concrete properties, including constructability. In addition, CNCs had no significant impact on mechanical and electrical properties and hygrothermal responses. The impact of CNCs on the long-term durability of the slabs will be studied.

A typical concrete freeway lane mile would require 44-45 dry tons of cellulosic fiber or the equivalent of about 3.5 acres of woody biomass from thin-from-below forest thinnings when using 0.2% CNC mix with PLC.

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