Low-Carbon Concrete Pilot Project: Evaluating Set Times and Early Strength

This case study provides information on one of the City of Portland's low-carbon concrete pilot projects within the City's Bureau of Transportation.

May 2022

Carbon Leadership Forum Portland

Background

The City of Portland's 2016 Sustainable Supply Chain Analysis identified construction services as the top spend category contributing to the City's supply chain greenhouse gas (GHG) emissions. Within construction services, concrete is one of the most GHG-intensive materials typically used on City construction projects. As a result, in 2019, after gathering both internal and external stakeholder input, the City established its Low-Carbon Concrete Initiative to reduce the overall carbon intensity of the concrete mixes used on City projects. Part of the Initiative involves pilot testing different lower-carbon mixes to gather data on how these mixes perform. This case study provides information on one of these low-carbon concrete pilot projects. This pilot project focused on learning more about the set and early strength properties of lower-embodied carbon concrete mixes under different conditions.

Project Overview

Unlike the City's previous low-carbon concrete pilot projects which compared lower-carbon concrete mixes to 100% cement mixes within the same project, this pilot project focused on gathering data on the set and early strength gain properties of lower-embodied carbon mixes. Both the set and early strength gain properties of mixes can influence workflow, schedules, and thus, project costs. Understanding these properties can help concrete finishers better anticipate and plan for any needed changes from their status quo when moving to lower-embodied carbon mixes. For this pilot project, a Type I/II-50% slag mix and a Type 1L-30% slag mix were evaluated on sidewalk and driveway applications (see sidebar for more information on Type 1L cement). In addition, the Type I/II-50% slag mix was applied during different times of year and thus, different ambient temperatures to understand how temperature affected set and early strength of the high-slag mix. The following table provides more detail on the mixes used for this pilot project.

Type 1L Cement

As per ASTM C595, the term portland-limestone cement (Type 1L) refers to a hydraulic cement in which the limestone content is more than 5% but less than or equal to 15% by mass of the blended cement.
In other words, with Type 1L cement, up to 15% raw (uncalcined) limestone is ground with calcined clinker. Type 1L has a lower global warming potential (GWP) due to the reduction in clinker use.

Table 1: Low-Carbon Pilot Test Mixes

Design Strength (PSI @ 28 days)	% Cement/SCM[a]	Lbs Cement / yd3[b]	Lbs Slag / yd3[b]	GWP[c]
3300	50% Type I/II cement-50% slag	287	286	189.4
3000	70% Type 1L cement-30% slag	371	159	178.1

a-SCM=Supplemental Cementitious Material
b-per the supplier's Design Mix, actual batch levels may vary slightly
c-GWP=Global Warming Potential (measure of embodied carbon)

Concrete finisher crews were asked to provide observations regarding set times, and maturity testing methods were used to measure early strength gain (see sidebar for more information on concrete maturity testing). As per other pilot projects, for each pour, the City's technicians from the Bureau of Environmental Services' Materials Testing Lab (BES MTL) tested the concrete for entrained air, slump, temperature (ambient and concrete) and collected cylinders for compressive strength tests according to ASTM standards. Compressive strength tests were conducted at the 7, 14, 28, and 56-day intervals.

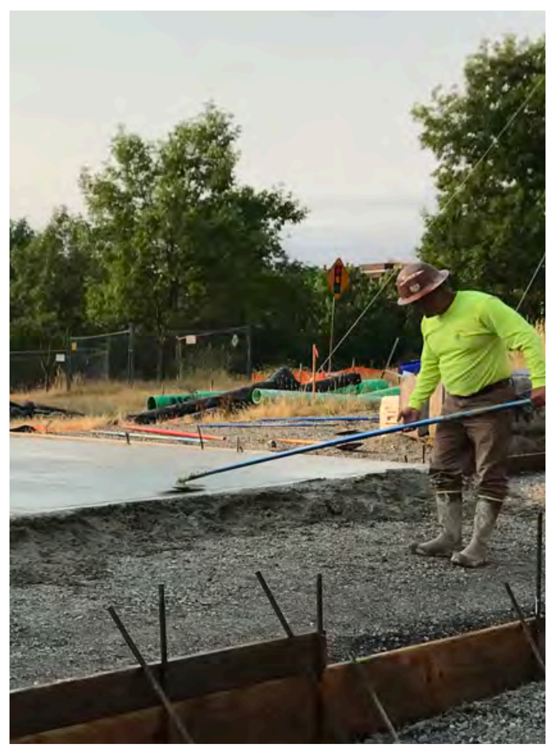
Concrete Maturity Testing

The maturity method is an approach to predict the early age strength gain of concrete, using the principle that the concrete strength is directly related to the hydration temperature history of cementitious paste. It is based on an equation that takes into account concrete temperature, time, and strength gain. The maturity concept for estimating the strength gain of concrete is described in ASTM C1074, Standard Practice for Estimating Concrete Strength by the Maturity Method. To implement maturity testing, a mix-specific maturity curve must be developed in the lab ahead of time. Then, at the construction site, concrete maturity sensors (many now are wireless) are placed in the concrete as soon as it is poured. The sensor collects and stores temperature data over time, which is then uploaded to a receiver device. Using the sensor data against the mix's maturity curve, the compressive strength of the in-place concrete can be estimated.

Results - Set Time

Regarding the 50% slag mix, results from this pilot project show that a high-slag percentage can significantly affect the mix's set time on a project; however, some of that affect can be mitigated with the use of an accelerator additive. When the 50% slag mix was poured in June for a driveway application (ambient temperate at pour = 66°F), the concrete installation crew reported that the difference in set time from their usual 100% cement mix increased from about 2.5hrs to 3.75hrs. When the crew poured the same 50% slag mix in December for another driveway (ambient temperature at pour = 35°F), they commented that the set time was even longer - about 5hrs.

Given the longer set time observations with the 50% slag mix in the first few pours, the crew then tested the 50% slag with different amounts of accelerator added to see if that would speed up the set time (on a sidewalk application). A 0.5% accelerator addition did not result in an observable difference, but with 2% accelerator added, the crew reported that the 50% slag mix, in cool ambient temperatures (~40°F), set up "almost as fast as" their status quo 100% cement mix. In terms of the mix's embodied carbon, the concrete producer reported that the addition of the 2% accelerator increased the mix's GWP by approximately 1.4%.



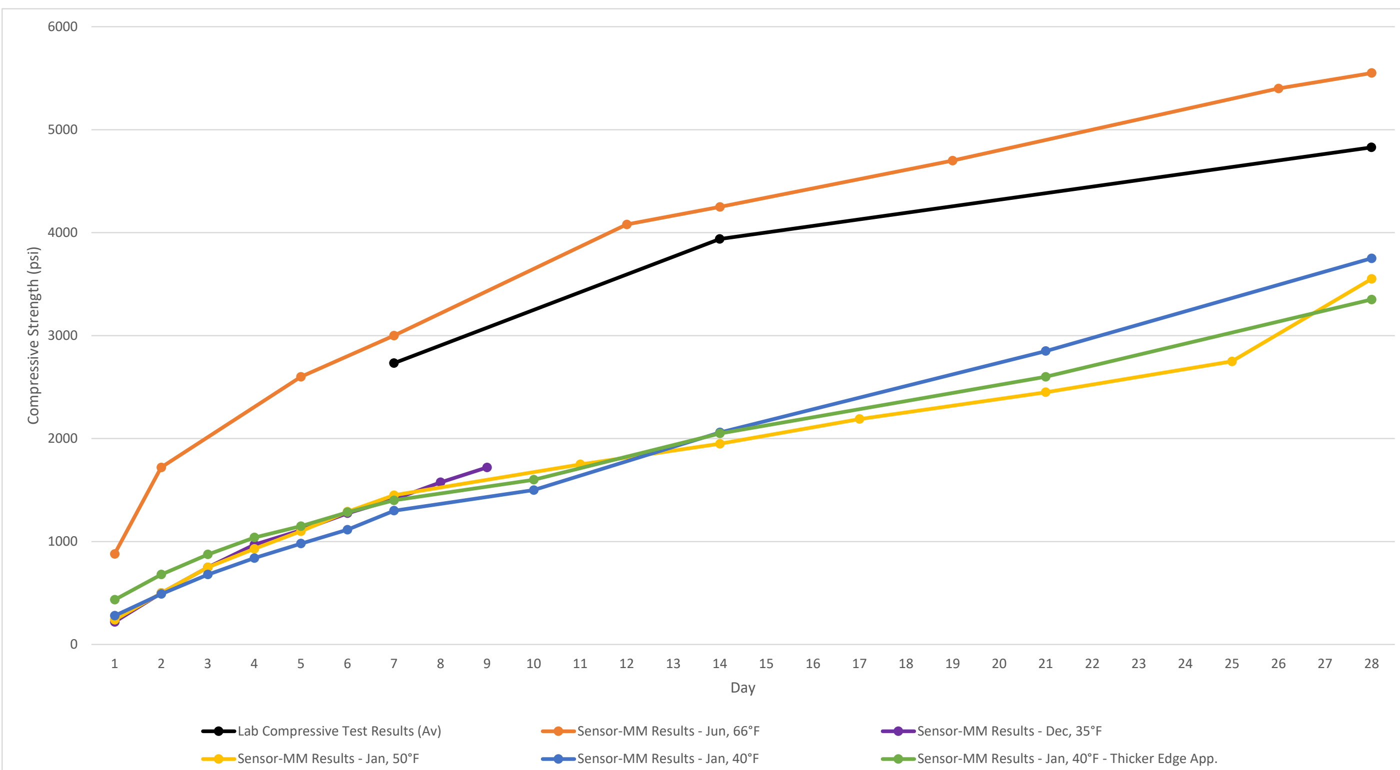
Lastly, the crew tested the Type 1L-30% slag mix (on a sidewalk application) to compare the set time with the Type I/II-50% slag mix in cool ambient temperatures (~40°F), since the Type 1L-30% slag mix is also a lower-embodied carbon mix (even lower GWP than the 50% slag mix). Anticipating a slower set time, the crew first tried the Type 1L-30% mix with 1% accelerator and hot water. The crew found that that combination actually set up too fast. For their second Type 1L-30% slag sidewalk application, they scaled back to only using hot water, which they reported set closer to their status quo 100% cement mix.

Results - Early Strength

In addition to evaluating set times, the pilot partners utilized the concrete maturity method to assess the early strength properties of high-slag mixes in the field under different conditions: different ambient temperatures (summer vs. winter) and application thickness (sidewalk/driveway vs. thicker border edge). For each of the pours subject to the maturity testing, the same Type I/II-50% slag mix was used and BES MTL collected cylinders for their standard compressive strength tests. Figure 1 compares the maturity results from each of the pours to the average of all the compressive strength test results (through day 28). Figure 2 is a close-up of the same data but through day 7 to better show the differences in early strength due to different ambient temperatures and application thickness. Overall, the data shows that ambient temperature significantly impacts early strength gain, with the summer temperatures lending to early strengths that better accommodate aggressive work sequence timelines. Although not as significant an impact as the ambient temperature in this study, the thickness of the application (due to heat of hydration) also increased early strength gain.

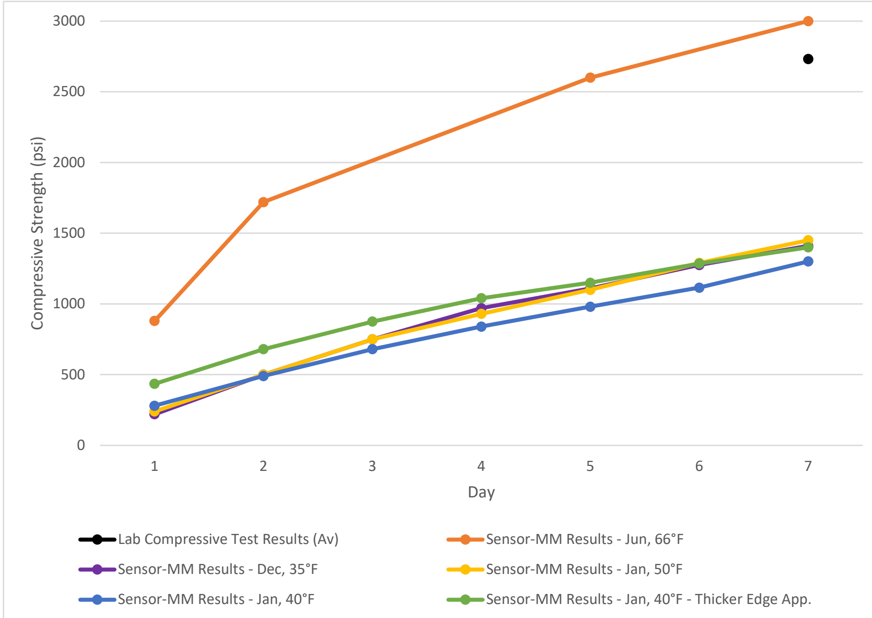
Maturity Testing Sensor

Figure 1
Maturity Results for 50% Type I/II-50% Slag Mix Under Different Ambient Temperature & Application Thickness (Driveway & Sidewalk) – 28 days



Although limited in scope, this pilot project's maturity testing also demonstrates how the approach could help inform crews working with low-embodied carbon concrete mixes on projects with strength-critical sequencing. The maturity method would not be a substitute for mix performance compliance procedures, but it could help crews in the field as they navigate the variables contributing to early strength gain.

Figure 2
Maturity Results for 50% Type I/II-50% Slag Mix Under Different Ambient Temperature & Application Thickness (Driveway & Sidewalk) – 7 days



Conclusions

This pilot project demonstrates that in moving to lower-embodied carbon concrete mixes, it is helpful to understand the various properties of the cementitious materials and their impacts on finishability. While high percentages of slag in a mix will lower the early strength of a mix or increase set time, the extent of those impacts varies significantly with ambient temperature. Lower-carbon mixes featuring a combination of Type 1L cement and up to 30% slag may have very little impact on set time and early strength and thus, the concrete crew's expectations (see also some of the other City low-carbon concrete case studies featuring the use of Type 1L-30% slag mixes). When crews understand various cementitious material properties, they can work with the concrete supplier to include additives as needed to improve the desired mix trait (such as using accelerator to reduce set times). Doing will help the crew manage schedules and predict cost impacts. Using tools like maturity testing can also help crews navigate early strength concerns amid many variables.

Overall, this pilot underscores the growing importance of customers (designers/concrete crews) collaborating with their concrete supplier in selecting and fine-tuning lower-embodied-carbon concrete mixes per specific applications, environmental conditions, and performance needs.

Disclaimer:
This publication was developed by members of the Carbon Leadership Forum Hub in Portland and the findings presented within are the perspectives of the authors.

Author/contact:
Stacey Foreman (stacey.foreman@portlandoregon.gov)

CLF Info:
The Carbon Leadership Forum accelerates the transformation of the building sector to radically reduce the embodied carbon in building materials and construction through collective action. We pioneer research, create resources, foster cross-collaboration, and incubate member-led initiatives to bring embodied carbon emissions of buildings down to zero. We are architects, engineers, contractors, material suppliers, building owners, and policymakers who care about the future and are taking bold steps to decarbonize the built environment, with a keen focus on eliminating embodied carbon from buildings and infrastructure. To learn more, and to join the movement to decarbonize building materials and construction, visit https://carbonleadershipforum.org