Low Carbon Concrete in Residential Construction

This pilot project demonstrates the use of low carbon concrete mixes in residential foundations and slabs.

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CLF Carbon Leadership Forum Portland
State of Oregon DEQ Department of Environmental Quality
BIRDSMOUTH Design | Build
WCP WILSONVILLE CONCRETE PRODUCTS

Background

In 2017, the Oregon Department of Environmental Quality (ODEQ) began working with concrete producers to measure and disclose the greenhouse gas (carbon) impacts of concrete mixes through carbon disclosure labels. The labels, called environmental product declarations (EPDs), are independently third party verified and help inform lower carbon purchasing decisions.

EPDs are used often in commercial construction to source lower carbon materials. They are also being used for public projects in Oregon. For example, the City of Portland has been requiring concrete EPDs since January 1st, 2020 and recently set carbon limits per strength class that will take effect January 1st, 2023. EPDs are also being used on some State of Oregon buildings, which has been encouraged through executive orders.

Lower carbon concrete mixes are widely available in Oregon and are typically cost neutral on a cubic yard basis. These mixes typically use less Portland cement and more supplementary cementitious materials (SCMs), like slag, as a binder for the aggregates in a concrete mix. Slag is a byproduct of steel manufacturing and makes an excellent binder in concrete mixes. The biggest construction challenge with lower cement mixes with greater SCM content is that they typically gain strength slower than mixes using 100 percent cement binder.

This pilot project builds on an already robust set of low carbon concrete pilot projects led by the City of Portland to better understand the opportunities and limitations of lower carbon mixes for infrastructure projects. This project focused on residential construction to help broaden the published examples and applications of lower carbon concrete.

Project Overview

This pilot project was designed to test lower carbon mixes in residential construction applications. The goal was to understand how the mixes perform, both in terms of technical requirements, workability and cost. The concrete finishers were interviewed to gauge the workability and finishability of the mix compared to their "usual" mixes. The finishers were an experienced crew (15+ years) that have only used 100% cement mixes in the past.

The residential home was designed and built by Birdsmouth Construction. The site and concrete work subcontracted to Two Mountain Company. This single dwelling home is being constructed to the Passive House standard and also employing methods to reduce overall concrete consumption by utilizing a novel concrete-free slab, as detailed in this Fine Home Building article from March 2022.

Wilsonville Concrete Products was the concrete supplier. All mixes utilized a Type 1L Portland Cement, which is becoming more widely available in the Portland area and has a reduced carbon footprint compared to the more typical Type 1/2 Portland cements used. All mixes had EPDs, which allowed the project team to know the carbon footprint of each mix, as detailed in Table 1.

Table 1. Lower Carbon Pilot test mixes utilized

Element	*Specified strength (psi)*	*Mix strength (psi)*	*Type 1L cement (lbs)*	*Slag (lbs)*	*Total cementitious (lbs)*	*% SCM*	*water cement ratio*	*air entrained?*	*GWP (kgCO2e) /yd3*
Foundation stem wall	2500	3000	235	235	470	50%	0.55	yes	132
Exterior flatwork	2500	3000	329	141	470	30%	0.55	yes	160
Garage slab	2500	3000	329	141	470	30%	0.55	no	160

Structural concrete specifications in the project plans called for 2500 psi mixes with a .46 water/cementitious (w/cm) ratio for all air entrained concrete, a .58 w/cm ratio for non-air entrained mixes, and a cement minimum of 470 lbs. Alternative w/cm ratios were allowed when substantiated in accordance with ACI 318, which this project chose to utilize. To test performance, during each pour, an independent 3rd party testing company was hired to test the concrete for entrained air, slump, temperature (ambient and concrete) and collected cylinders that would be used for compressive strength tests. Compressive strength tests were subsequently conducted at the 7, 28, and 56-day intervals as shown in Figure 1. The exception was the 50% slag mix, which was not tested at 7 days due to an administrative error by Oregon Department of Environmental Quality.

To test workability, at each pour, the concrete finishers were interviewed to assess how they thought each mix performed in terms of how the mix flowed, reacted to vibration, troweled/finished, impacted application time, and affected flashing.

Results

Overall, the low carbon mixes met the concrete performance specifications, posed some first-time challenges to the concrete finishers, didn't cause any major delays in the project schedule, and lowered the total carbon footprint of the mixes by 42% compared to the "business as usual" mixes. All mixes achieved the specified compressive strength of 2500 psi well ahead of the 28-day specification, with all mixes topping out with strengths over 4000 psi by day 56.

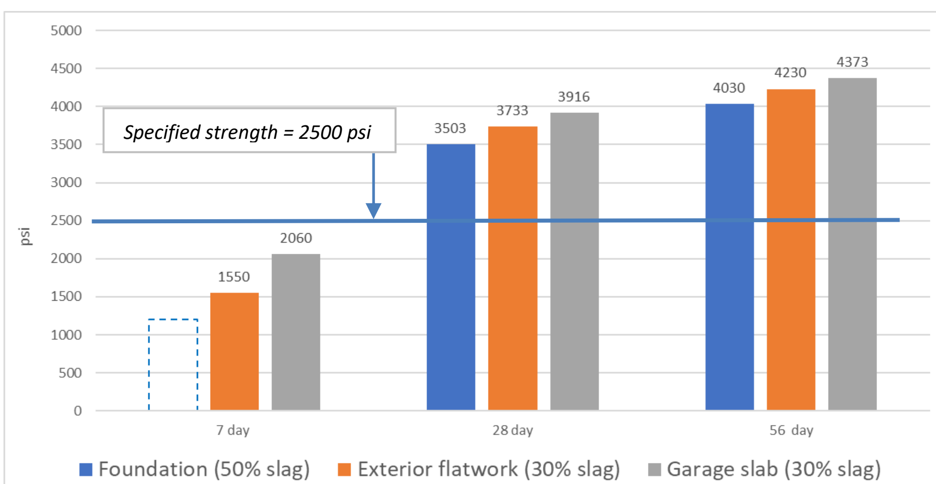

Figure 1 – Compressive Strength Results

Figure 2 shows that the concrete used on this project was able to achieve a 27% carbon reduction compared to the Pacific Northwest (PNW) Regional benchmark mixes from the National Ready Mix Concrete Association (NRMCA), and a 42% reduction compared to a 100% cement mix. It's important to note that carbon reductions were achieved by reducing cement contents and not by simply increasing slag contents to meet a percent slag target.

In terms of workability, the concrete finishers for the foundation saw very little to no difference in placing or pumping the concrete. Formwork stayed in place longer than normal and cold temperatures slowed curing, causing some surficial tearing during the formwork removal. The flatwork contractors saw little difference in the exterior slabs but did see a difference in finishing approach for the hard troweled slab. See the *Discussion* section below for more details on the finishing differences experienced for these contractors.

Finally, the total cost of the concrete work on this project increased by 5% due to a combination of slightly higher material and labor costs.

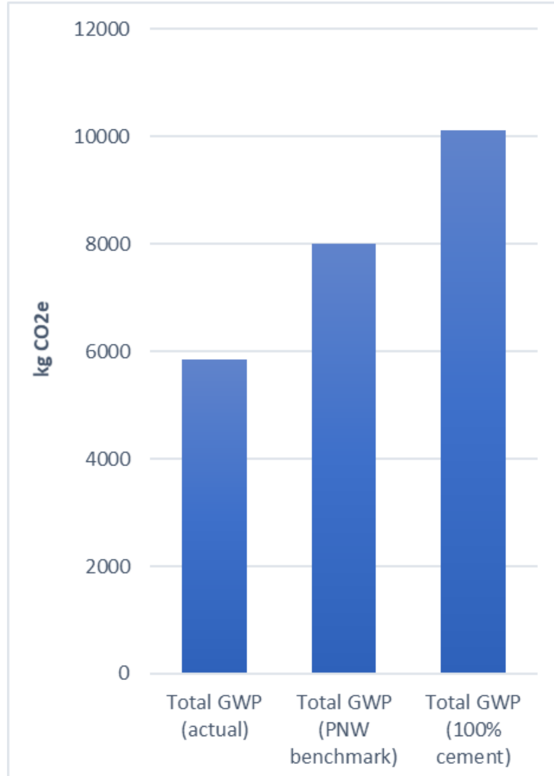

Figure 2 – Total project concrete GWP

Discussion

Foundation footing and stem wall

This project utilized a "2-pour" foundation approach where the footing was poured separately from the stem wall. The contractor reported this method saves concrete by having a slightly smaller footing compared to a mono pour. The workability and pumpability of the 50% slag foundation mix was excellent with no reported problems. The contractor reported that the mix felt less "creamy" than higher cement mixes. However, the mix was easy to work around the footing rebar and vibrate into the stem wall formwork. Formwork would normally be stripped the next day but was delayed until day 3 for this mix. Even at 3 days, there was still some surficial tearing during form stripping. The contractor also found it very easy to drive a nail through the concrete on day 3 during form stripping when it would normally be much harder.

Photo 1 – cracking at foundation anchor bolt

The contractor reported that oiling the forms next time could help prevent the tear out. The other main challenge with this mix were small non-structural cracking around the anchor bolts (photo 1). This was likely due to excess water being added on site since the measured slump was much higher than the specified slump. Excess water can cause more cracking and even contribute to a slower cure and lower strengths. Fortunately, these minor issues can be avoided with water control, oiled forms, and a longer planned period for form stripping.

The final challenge with the foundation pour were the cold temperatures during the pour and initial curing. The air temperature was 36 degrees Fahrenheit at the time of the pour and during initial curing. Cold temperatures combined with the very low cement mix used in this project can further elongate cure times.

Exterior slab

A 30% slag mix with Type 1L cement and air entrainment was utilized for the exterior slabs, which we're primarily used for walkways. The flatwork subcontractor reported good pumping and normal workability during placement. Although the initial float was a bit "sticky" the contractor leveled out the high spots with a hand trowel and let it set up for about 30-45 minutes before applying the broom finish. The set time was comparable to a 100% percent cement mix. However, the concrete delivery truck was delayed in traffic for an hour, which may have contributed to a comparable set up time.

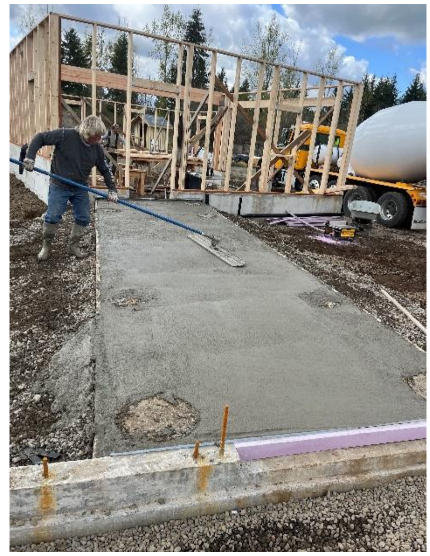

Photo 2 – bull floating a walkway

Garage slab

The 30% slag mix with type 1L cement and without air entrainment was used for a hard troweled garage slab. This contractor reported that the mix started to "flash" faster than he was used to. Since he had only one helper on hand, they didn't have time to vibrate the mix. The contractor attributed the somewhat "cakey" finishing trowel work to less "cream" coming to the top since the mix wasn't vibrated. The contractor said he would have brought 2 workers instead of 1 if he used this mix again. Additionally, while a "regular 100% cement" concrete slab would have allowed workers to begin lightly using the slab the next day, the crew decided to stay off this slab for a full 3 days to avoid marking or damaging it. Finally, the concrete finisher returned to cut control joints 6 days following the cure, but the concrete wasn't hard enough to cut yet. He returned on day 12 to cut the control joints without any issues.

Photo 3 – pouring the garage slab

Some of the "sticky" or "cakey" nature of the concrete during curing may have been due to dehydration of water on the surface. A 100% cement mix used in a slab tends to produce "bleed water" that can provide a layer of dehydration protection in the slab. In some cases, higher slag mixes can create less bleed water and can greatly benefit from using dehydration sprays directly after the initial bull floating. It's not entirely clear why this mix began "flashing" faster than the contractor was prepared for, especially since lower carbon mixes tend to cure slower than conventional mixes.

Overdesign

It's important to note that once fully cured, these mixes will have almost double the required strength needed for residential construction. This is partially due to the need to pump the concrete into the foundation and slab locations. Pumping requires a wetter and creamier mix, which typically means a minimum of 470 lbs of cementitious content per cubic yard of concrete. When pouring straight from a truck's chute, you can design mixes with lower cement content.

Cost
There was a 5% cost premium for the concrete work in this project. This may be typical when using concrete finishers unfamiliar with the lower carbon mixes. In fact, the concrete sub-contractor reported that he may bid future jobs with a 7-10% premium dependent on the supplier and experience of the finishers. In some cases, the onsite labor hours will increase and in other cases, contractors may learn to adjust their schedules and crew size to lower carbon mixes. The cost of lower carbon mixes are typically cost neutral, but residential contractors may see a small total cost increase (~5%) as the labor market adjusts to new methods and materials.

Recommendations

Since foundations don't require detailed finishing techniques, they are a low-risk application for starting to use lower carbon mixes. A 50% slag mix, like used in this project, is feasible in today's residential market in Oregon. Formwork will need to stay on longer (especially in cold weather) and be oiled more frequently than normal. Controlling water and maintaining the design slump are important for the proper curing of any concrete mix, including lower carbon mixes. Overall, foundations are an excellent place for residential builders to start using lower carbon mixes.

For flatwork, 30% slag mixes are possible for all residential applications with potential adjustments to crew size, finishing process, and cure time. Use of dehydration sprays and longer protection periods for the slabs will be needed. If crews are used to 100% cement mixes, consider phasing in higher and higher slag mixes for the flatwork as crews adjust to the new finishing process and timeline.

Finally, as with this project, there are often "standard" concrete specifications that may limit the ability to use lower carbon mixes. Removing cement minimums, allowing for larger water cementitious ratios, and specifying strengths at 56 days instead of 28 days for applications like foundations are other elements to consider in residential specifications.

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