Research Corner

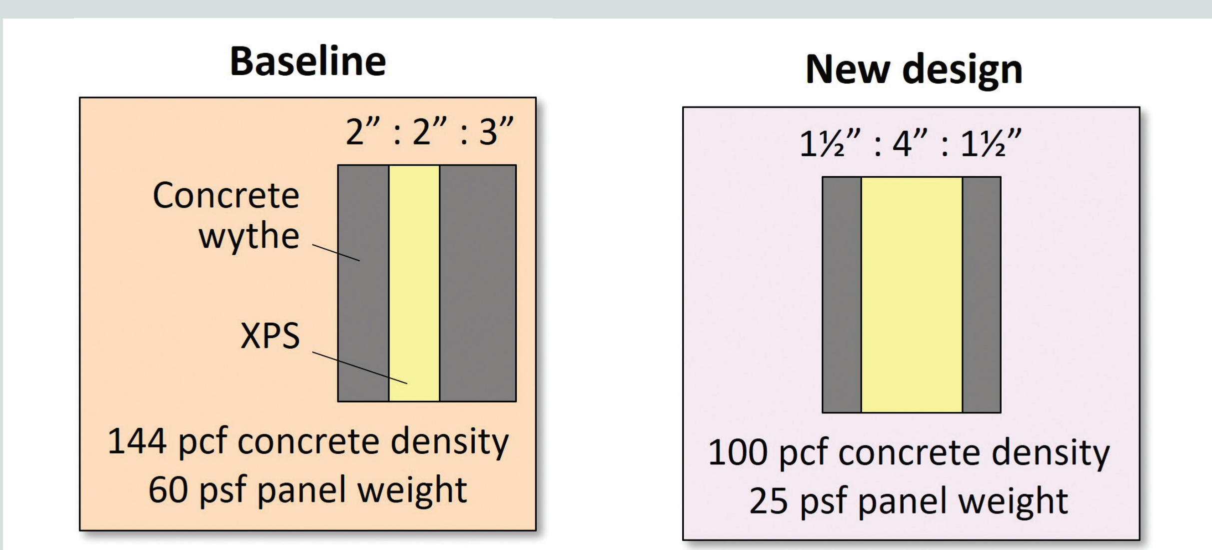
ORNL next-generation materials research

Diana E. Hun and Jared Brewe

In 2017, PCI and Oak Ridge National laboratory (ORNL) engaged in a Cooperative Research and Development program, the results of which are discussed in *Next Generation of Architectural Precast Insulated Wall Panels*.[1] The program was primarily funded by the U.S. Department of Energy and accomplished as a partnership between ORNL, the University of Tennessee (UT), and PCI. This Research Corner has excerpts from the project summary final report; provides an overview of the work performed by ORNL, UT, and PCI; and presents some of the resulting technologies. Additional information about the project and outcomes is provided in Hun.[1]

The project objective recognized that the building envelope, an important determinant of the amount of energy required for space conditioning, is critical for reducing building energy loads. The project objective also recognized the benefits of off-site construction, including fewer construction defects, fewer on-site workers, shorter on-site construction time, and less on-site waste. The conceptual outcome was that architectural precast concrete insulated wall panels would be more widely used, including in building envelope retrofits, if they were lighter, had a shorter production time, and had higher thermal performance.

The project also included the development of three-dimensional (3-D) printed molds for precast concrete and the development of self-healing sealants. The *Guide on 3D Printed Molds for Precast Concrete* (PCI-ORNL-01-21), an outcome of this collaboration between PCI and ORNL, summarizes the background information and guidance on using 3-D printed molds to fabricate precast concrete.



Typical assembly of precast concrete insulated wall panel and new design to lower the weight of the panel by more than 50%.

50% lighter precast concrete insulated wall panels

A common precast concrete insulated panel consists of a 2 in. (51 mm) thick concrete wythe, 2 in. thick insulation, and a 3 in. (76 mm) thick concrete wythe. The concrete mixture typically has a density of 144 lb/ft^3 (23.1 kg/m^3); therefore, the panel weight is about 60 lb/ft^2 (290 kg/m^2). To lower the weight of the panel by at least 50%, the thickness of the wythes was decreased to 1.5 in. (38 mm) and the density of the concrete reduced to 100 lb/ft^3 (1600 kg/m^3). These two changes reduced the panel weight to 25 lb/ft^2 (120 kg/m^2). This thinner wythe design requires a new concrete mixture with appropriate early tensile strength so that the panels can be removed from the casting beds at the typical production rate, as well as new erection and lifting inserts made of nonmetallic materials since the necessary concrete cover for steel inserts cannot be provided in 1.5 in. thick wythes. The following sections summarize the developed designs.

Concrete mixture for 1.5 in. thick wythes

For the new lightweight early tensile strength concrete mixture, the mixture specifications for a 1.5 in. (38 mm) thick wythe were established by the PCI Research Advisory Committee to be as follows:

- density ≤ 100 lb/ft^3 (1600 kg/m^3)
- 12-hour flexural strength ≥ 600 psi (4100 kPa)
- 28-day compressive strength ≥ 8000 to 10,000 psi (55 to 69 MPa)
- self-consolidating

Lab-scale trials were performed at ORNL and the University of Tennessee at Chattanooga on raw materials commonly used in precast concrete production combined with supplemental binders and other lightweight materials to achieve the desired properties. The resulting mixture included the following materials: Type III portland cement; metakaolin; calcium sulfoaluminate cement (CSA); ⅜ in. (9 mm) lightweight expanded slate aggregate; lightweight fine expanded slate aggregate; expanded glass fine aggregate; water; CSA cement set retarder; high-range water-reducing admixture; hydration controlling admixture; and reinforcing nonmetallic lightweight fibers. The mixture was scaled at a precast concrete producer with favorable results. In addition to providing an approximately 58% lighter wall panel, the panel also has 40% less concrete and embodied energy than the baseline panel.

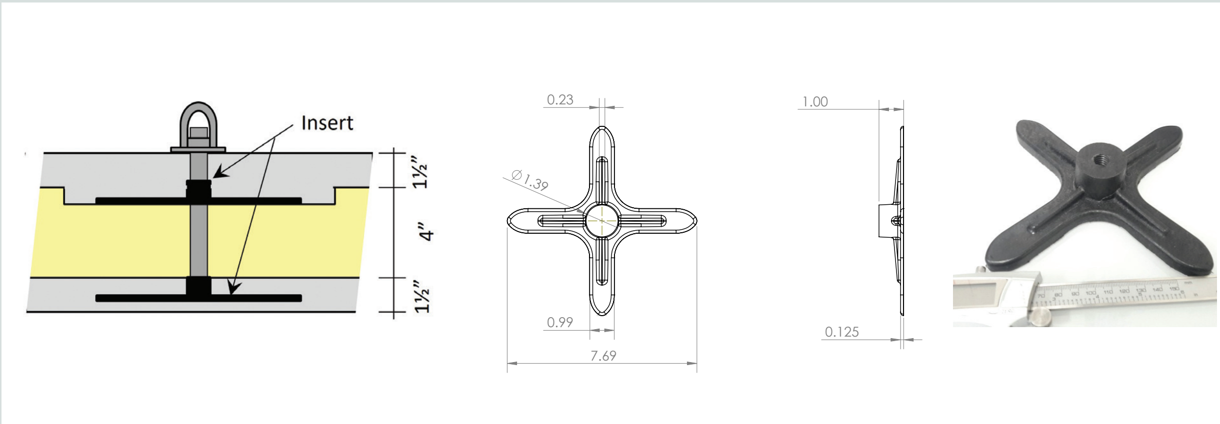
Noncorroding inserts

The PCI Research Advisory Committee identified that three inserts were needed for the precast concrete panel with 1.5 in. (38 mm) thick concrete wythes: stripping and lifting inserts, erection inserts, and bearing and bolted tieback connection inserts. The research team at ORNL and the University of Tennessee worked to develop noncorroding, nonmetallic inserts to meet the project requirements.

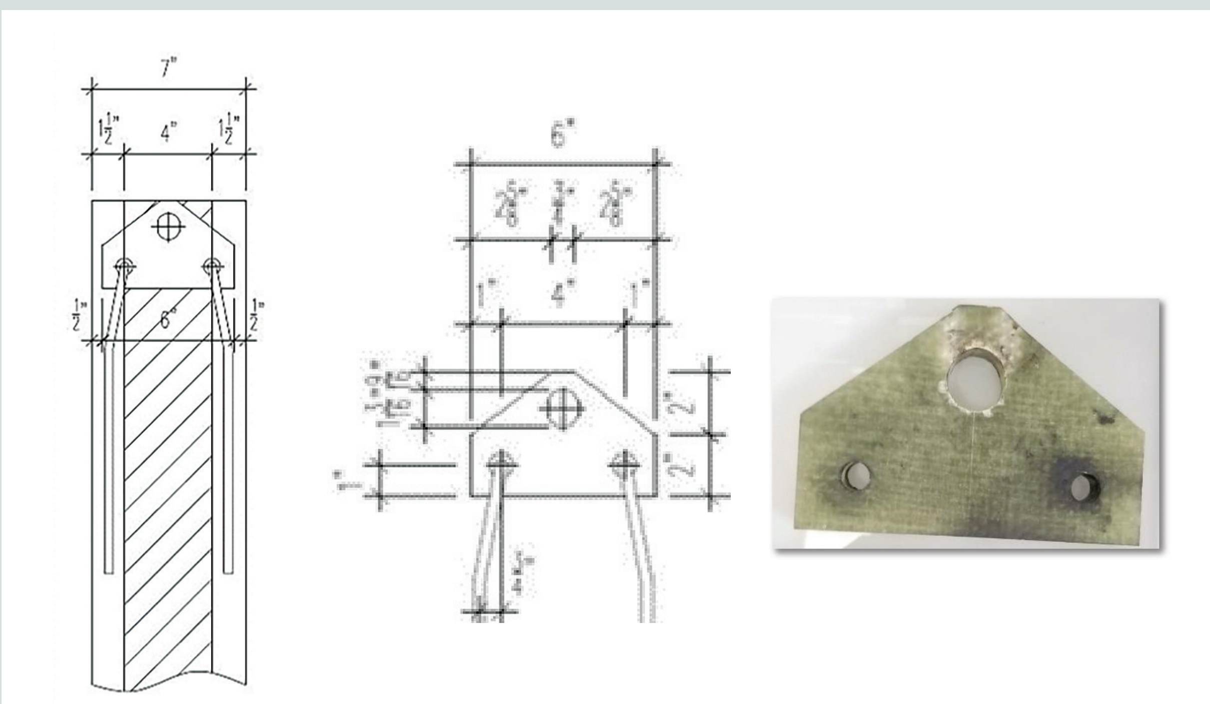
Stripping and lifting inserts For the stripping and lifting inserts, the PCI Research Advisory Committee set the required tensile strength to be at least 10,000 lb (4500 kg). This insert was designed as a thermoplastic polyurethane with discontinuous glass fibers to achieve the required strength and noncorrosive performance. To achieve the target strength, a locally thickened wythe was required to prevent concrete breakout.

Erection inserts For the erection inserts, the PCI Research Advisory Committee set the required tensile strength to be at least 12,000 lb (5400 kg). This insert was designed as a continuous glass-fiber-reinforced epoxy com-

1.5 in. (38 mm) thick concrete wythe using the developed concrete mix.



Noncorroding stripping lifting insert for precast concrete insulated panels with 1.5 in. (38 mm) thick wythes and 4 in. (100 mm) thick insulation.



Noncorroding erection lifting insert design for precast concrete insulated panel with 1.5 in. (38 mm) thick wythes and 4 in. (100 mm) thick insulation.

posite to achieve the required strength and noncorrosive performance. One of the inserts exceeded the required tensile strength with a capacity of 18,950 lb (8600 kg).

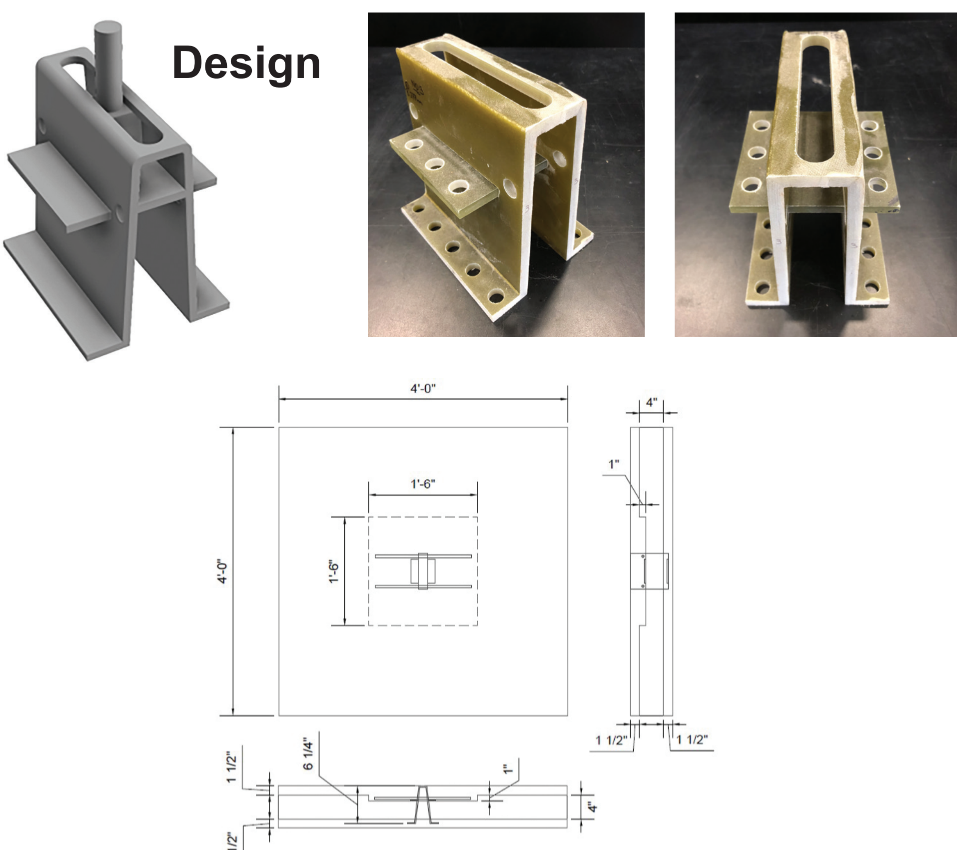
Bearing and bolted tieback connection inserts For the bearing and bolted tieback connection inserts, the PCI Research Advisory Committee set the required tensile strength to be at least 10,000 lb (4500 kg). This insert was also designed as a continuous glass-fiber-reinforced epoxy composite to achieve the required strength and noncorrosive performance.

50% faster production time

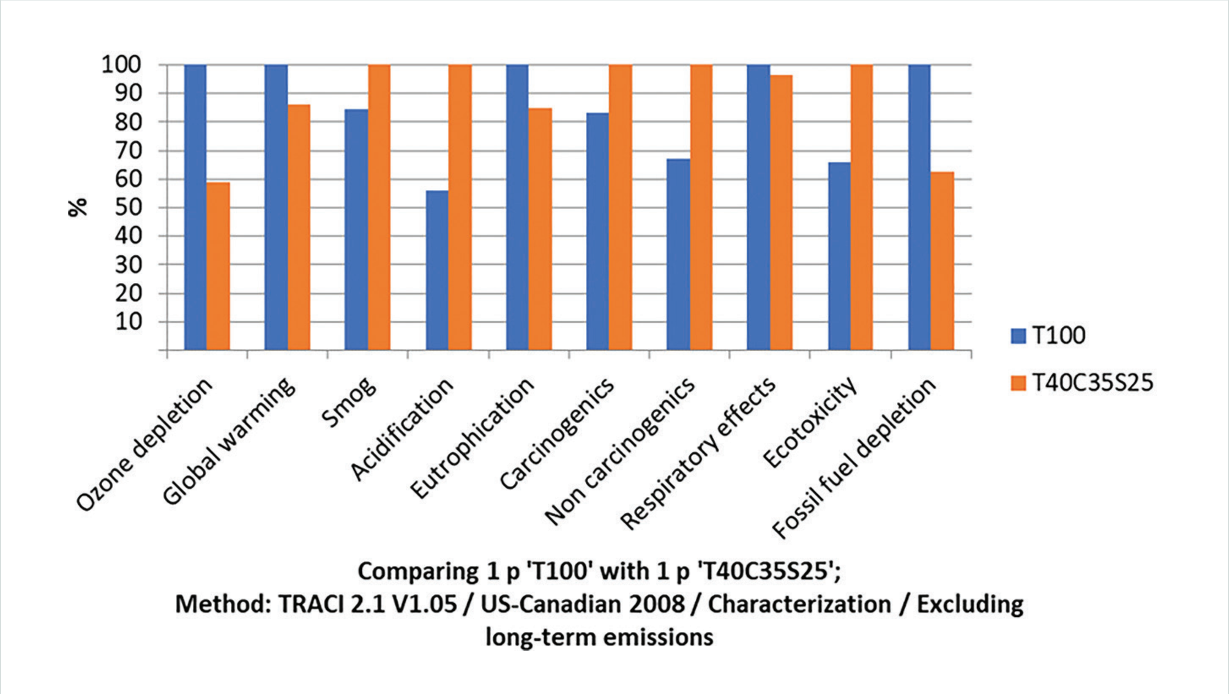
Concrete mixture to turn casting beds twice per day

Most precast concrete plants use their casting beds once per day mostly because their typical concrete mixtures develop the required strengths in 12 to 18 hours. To shorten production times, the project sought to develop a concrete

Scale-up of concrete mixture.



Noncorroding bearing and bolted tieback connection insert design for precast concrete insulated panel with 1.5 in. (38 mm) thick wythes and 4 in. (100 mm) thick insulation.



Preliminary results for concrete mixtures with 100% Type III cement (T100) and 40% Type III cement, 35% CSA, and 25% GGBFS (T40C35S25).

mixture with faster strength gain, which would allow precasters to cast twice per bed per day.

Although compressive strength is typically the specified material property, the concrete flexural (tensile) strength development will be the primary material property to prevent crack formation during stripping and handling and to shorten production times. Typical concrete mixtures used in production attain a flexural strength of approximately 600 psi (4100 kPa) at 12 hours. Therefore, the PCI Research Advisory Committee established the following specifications for a twice-per-day mixture:

- 6-hour flexural strength ≥ 500 psi (3400 kPa)
- 6-hour compressive strength ≥ 3500 psi (24,000 kPa)
- self-consolidating
- cost of about $350/yd^3

The University of Tennessee at Knoxville (UTK) and ORNL performed lab-scale experiments to develop the concrete mixture that met the specifications.[3,4] A scale-up trial was performed, and the results matched the mechanical properties that were obtained in the lab.

Along with developing the mixture design, ORNL and UTK performed life cycle assessments to determine the embodied carbon reduction potential of the concrete mixture. The twice-a-day mixtures were compared with a baseline a mixture with 100% Type III cement (T100) and evaluated the effect of varying the proportions of Type III cement, CSA, and slag cement while maintaining the required mechanical properties. CSA and GGBFS were evaluated because these have lower global warming potential than Type III cement. The preliminary results from the mixture with 40% Type III cement, 35% CSA, and 25% slag cement (T40C35S25), show a decrease in the embodied carbon of the mixture by about 14%.

Improved thermal performance

Increasing the thermal performance of precast concrete insulated wall panels typically comes with the penalty of having to also increase the thickness of the panel. However, the ability to reduce the thickness of the concrete wythes to 1.5 in. (38 mm) provides an ability to increase the thickness of insulation without making the panel thicker, resulting in nearly twice the thermal performance for the same total wall panel thickness. The new concrete mixture and noncorroding inserts also enabled lowering the weight of the panels by more than 50%.

Ongoing collaboration

This initial collaboration between ORNL and PCI has led to additional opportunities to pursue research and development funding to support the precast concrete industry. Additional collaboration projects on high filler, low-water concrete mixture designs, a real-time evaluator for precast concrete panel erection, and a flat and level analysis tool, called FLAT, for real-time feedback on the location and dimensions of valleys and peaks in slabs are underway.

References

1. Hun, D. 2023. *Next Generation of Architectural Precast Insulated Wall Panels*. Oak Ridge National Laboratory. ORNL/TM-2023/3000. Oak Ridge, TN: Oak Ridge National Laboratory. https://info.ornl.gov/sites/publications/Files/Pub198540.pdf.
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3. Ghosh, D., A. Abd-Elssamd, Z. Ma, D. E. Hun. 2021. "Development of High-Early-Strength Fiber-Reinforced Self-Compacting Concrete." *Construction and Building Materials*, no. 226: 121051.
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