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Oak Ridge National Laboratory Next Generation of Architectural Precast Insulated Wall Panels

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Buildings and Transportation Science Division

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ABSTRACT

Off-site building envelope construction or prefabrication has many benefits including fewer construction defects, fewer onsite workers, shorter onsite construction time, and less onsite waste. The off-site building construction approach with greatest market success to date is precast concrete. However, precast production needs to develop new technologies to capture a larger share of the construction market. More specifically, architectural precast insulated wall panels would be more widely used if they were lighter, had a shorter production time, and had higher thermal performance. This report summarizes the technologies that Oak Ridge National Laboratory, the Precast/Prestressed Concrete Institute, and the University of Tennessee developed so that the next generation of architectural precast insulated wall panels are 50% lighter, 50% faster to produce, and/or have two times higher thermal performance.

1. INTRODUCTION

The building envelope is critical for reducing building energy loads. It is the starting point for energy-efficient buildings, a primary determinant of the amount of energy required for space conditioning, and an influencer on lighting energy needs. The building envelope also accounts for a large portion of all materials and embodied energy inherent in a building. It is of interest to determine how far we can go, in terms of energy savings, with passive approaches (e.g., insulation, air sealing) before having to resort to active approaches (e.g., heating, ventilation and air conditioning (HVAC) systems; other equipment; controls). Compared with active approaches, passive ones are less likely to go awry, perform more reliably over time, often have lower-maintenance costs, and have longer service lives. Nevertheless, even passive technologies can be defeated by poor construction workmanship and/or the difficulty of enforcing stringent passive envelope energy codes through site inspections.

Off-site building envelope construction or prefabrication has many benefits including fewer construction defects, fewer onsite workers, shorter onsite construction time, and less onsite waste. The off-site building construction approach with greatest market success to date is precast concrete. However, precast production has not changed much since the1960s and has captured only a modest share of the market. Architectural precast insulated wall panels would be more widely used if they were lighter, had a shorter production time, and had higher thermal performance. To attain these improvements, Oak Ridge National Laboratory (ORNL), the Precast/Prestressed Concrete Institute (PCI), and the University of Tennessee partnered to develop technologies that enabled:

1. 50% lighter precast insulated wall panels
2. 50% faster production time
3. Double thermal performance

The present report summarizes the designs and evaluations of the newly developed technologies and provides sources for more detailed information.

2. 50% LIGTHER PRECAST INSULATED WALL PANELS

A common precast insulated panel consists of 2”-thick concrete wythe, 2”-thick insulation, and 3-thick concrete wythe as shown in Figure 1. The concrete mix typically has a density of 144 lb/ft^3; therefore, the panel weight is about 60 lb/ft^2. To lower the weight of the panel by at least 50%, we decreased the thickness of the wythes to 1.5” and the density of the concrete to 100 lb/ft^3, which in turn reduced the panel weight to 25 lb/ft^2. This thinner wythe design required a new concrete mix 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 non-metallic materials since appropriate concrete cover for steel inserts cannot be provided in 1.5”-thick wythes. The following sections summarize the developed designs.

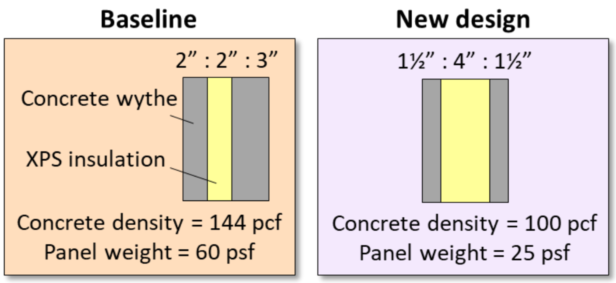


Figure 1. Typical assembly of precast insulated wall panel and new design to lower the weight of the panel by more than 50%.

2.1 CONCRETE MIX FOR 1.5”-THICK WYTHES

In consultation with PCI, the specifications for a concrete mix for lightweight, 1.5”-thick precast concrete wythes were determined to be:

1. Density $\leq$ 100 lb/ft^3
2. 12-hour flexural strength $\geq$ 600 psi
3. 28-day compressive strength $\geq$ 8,000 to 10,000 psi
4. Self-consolidating
5. Cost < $350/yd^3

Lab scale trials were performed at ORNL and the University of Tennessee at Chattanooga. The concrete mix that met the specifications is detailed in US patent #10,836,678 for High-Performance Concrete Mix for Precast Wythes (Hun et al. 2023). The mix was scaled at Gate Precast (Figure 2) with favorable results.

Figure 2. 1.5”-thick concrete wythe produced at Gate Precast using the developed concrete mix.

2.2 NON-CORRODING ERECTION INSERTS

For the non-corroding erection inserts, PCI set the ultimate tensile load to be at least 12,000 lb. We evaluated several fiber reinforced composites as described in US patent application #17/187,209 for Non-Corroding Erection Inserts for Precast Insulated Panels (Hun et al. 2021). Figure 3 shows the final geometry and an example of one of the inserts that met the required tensile strength.

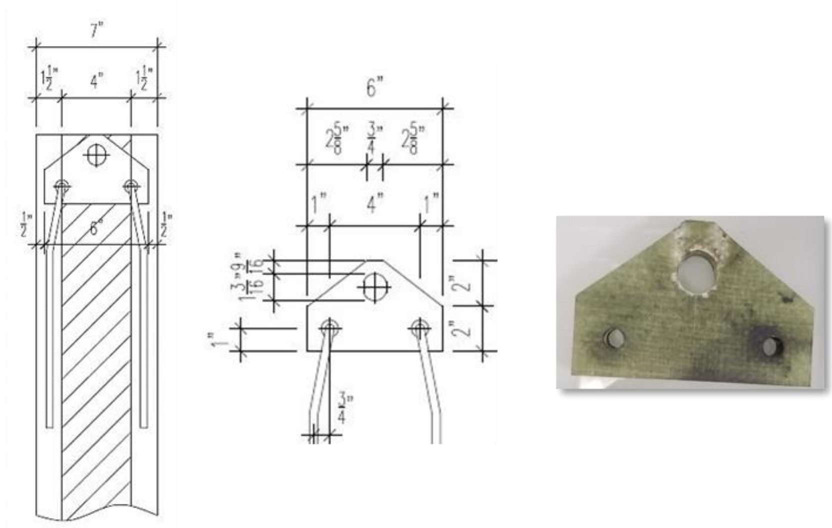


Figure 3. Non-corroding erection lifting insert design with ultimate tensile strength capacity of 18,950 lbs. The design is for precast insulated panels with 1.5”-thick wythes and 4”-thick insulation.

2.3 NON-CORRODING STRIPPING LIFTING INSERTS

PCI set the ultimate load of the stripping lifting inserts to be at least 10,000 lbs. Figure 4 shows the insert design and layout in the precast insulated panel. Lab tests were performed as described by Hayes et al. (2023). The fiber reinforced composite design that attained an ultimate load higher than 10,000 lbs. is detailed in US patent # 11,661,741 B2 for Non-Corroding Stripping Lifting Inserts for Precast Insulated Panels (Hun et al. 2023).

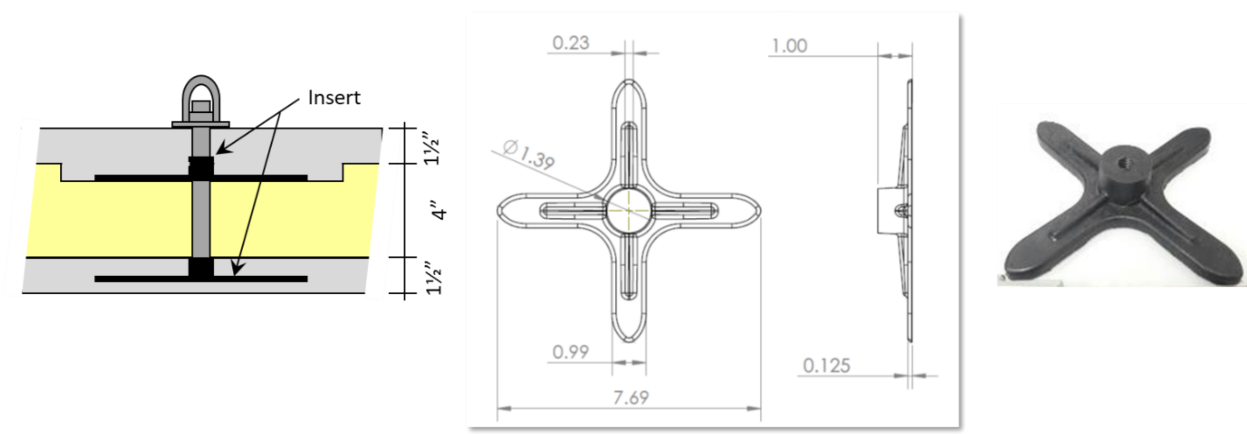


Figure 4. Non-corroding stripping lifting insert design with ultimate load capacity greater than 10,000 lbs. The design is for precast insulated panels with 1.5”-thick wythes and 4”-thick insulation.

3. 50% FASTER PRODUCTION TIME

3.1 CONCRETE MIX TO TURN CASTING BEDS TWICE PER DAY

Most precast concrete plants use their casting beds once per day mostly because their typical concrete mixes have been designed to attain the required flexural strength for demolding of ~600 psi at 12 hours. Therefore, when there is high demand, precasters have a long backlog, have to turn work down, or need to invest in increasing the size of their plants. An alternative option is a concrete mix that allows precasters to cast twice per day, which according to PCI requires these specifications:

1. 6-hour flexural strength ≥ 500 psi
2. 6-hour compressive strength ≥ 3500 psi
3. Self-consolidating
4. Cost ~$350/yd^3

The University of Tennessee at Knoxville and ORNL performed lab-scale experiments to develop the concrete mix that met the specifications (Ghosh et al. 2021, Ghosh et al. 2023). A scaleup trial was performed at Tindall (Figure 5) and the results matched the mechanical properties that were obtained in the lab (SGS 2021, Tindall 2021).

Figure 5. Scaleup of concrete mix at Tindall.

We performed life cycle assessments (LCAs) to determine how much we could reduce the embodied carbon of the concrete mix that enables two castings per day. We used as a baseline a mix with 100% Type III cement (T100) and evaluated the effect of varying the proportions of Type III cement, calcium sulfo-aluminate (CSA), and ground granulated blast furnace slag (GGBFS) while maintaining the required mechanical properties. CSA and GGBFS were evaluated because these have lower global warming potential than Type III cement. Figure 6 shows preliminary results from the mix with 40% Type III cement, 35% CSA, and 25% GGBFS (T40C35S25), that decreased the embodied carbon of the mix by ~14%. The Figure also includes comparisons for other environmental and health effects.

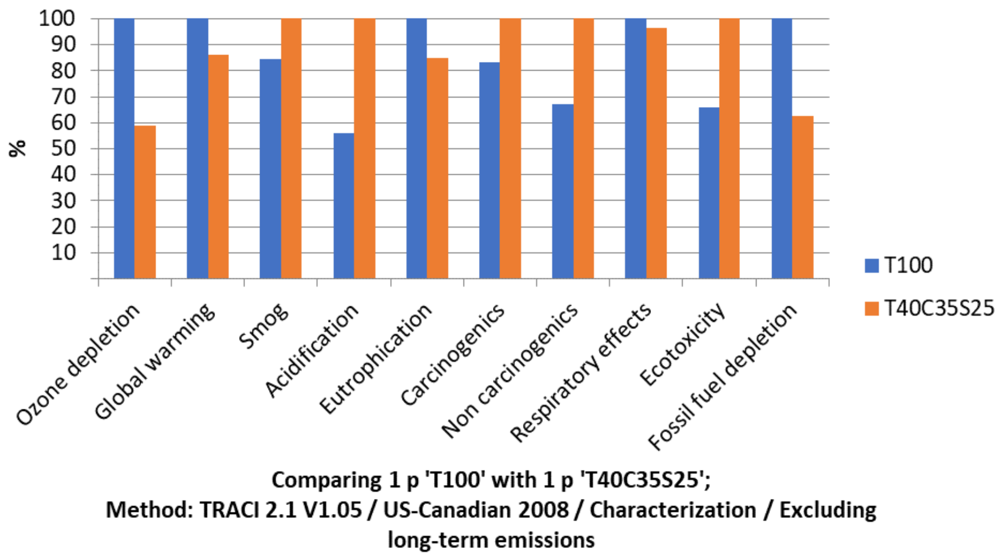


Figure 6. Preliminary results for concrete mixes with (1) 100% Type III cement (T100) and (2) 40% Type III cement, 35% CSA, and 25% GGBFS (T40C35S25).

3.2 3D PRINTED MOLDS FOR PRECAST CONCRETE

ORNL and PCI decided to explore 3D printing molds because the construction industry has been experiencing shortages in skilled labor for years and forecasts do not indicate that labor supplies will offset the losses. To this end, Gate Precast offered the One South First tower in Brooklyn, NY (Figure 7), as the project that would de-risk the adoption of 3D printed molds by the precast concrete industry. The project required the molds shown in Figure 8 that were used to cast parts that were designed to reduce energy use due to solar radiation indoors. Figure 9 shows the manufacturing process for the molds, and Figures 10 and 11 illustrate the final products.

Figure 7. One South First is a 45-story tower in Brooklyn, NY. Its precast concrete façade was designed to reduce energy use due to solar radiation. Rendering courtesy of CookFox Architects.

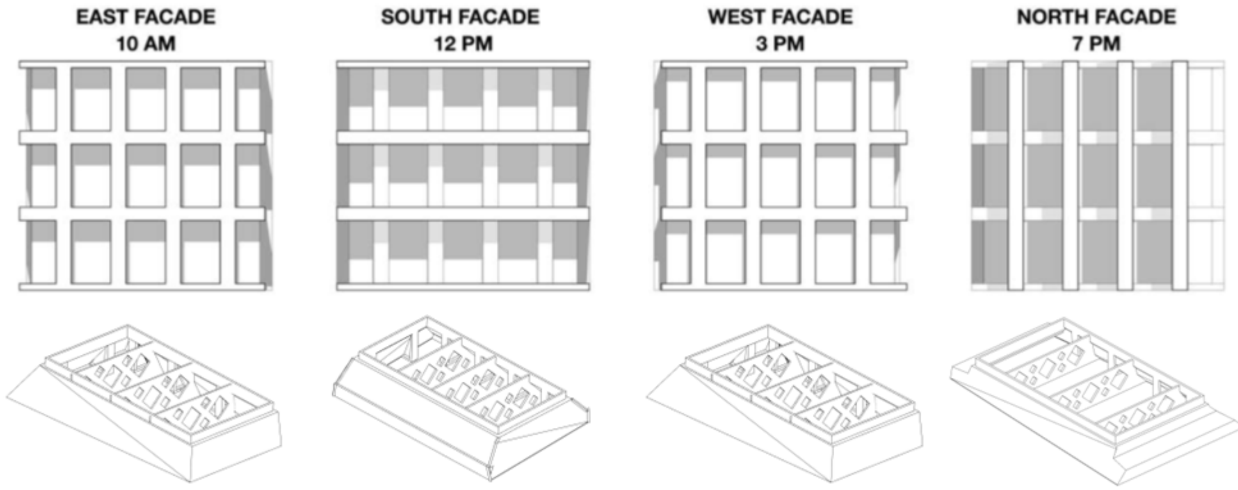
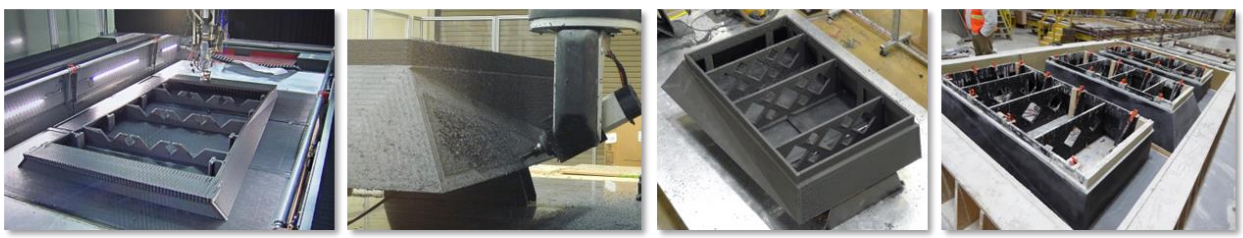


Figure 8. Mold designs that were selected for 3D printing because of their level of complexity and/or the number of times they would be used to cast concrete parts.



3D printing of mold with acrylonitrile butadiene styrene (ABS) reinforced with 20% carbon fiber (CF).

Machining of mold with computer numerical control (CNC) router.

~6'×~9'×~1.3' mold printed with ~500 lb of ABS/CF. Printing took ~8 hr. and machining ~6 hr.

3D printed molds on casting bed at precast plant before rebar installation.

Figure 9. Production steps for 3D printed molds.

Figure 10. Precast parts manufactured with 3D printed molds. Right photo courtesy of Gate Precast.

Figure 11. One South First is the first building with a precast concrete façade that was manufactured using 3D printed molds. Photo courtesy of CookFox Architects.

We describe the step-by-step design and printing process of the molds in the handbook that ORNL and PCI published titled Guide on 3D Printed Molds for Precast Concrete (Hun 2020). Some of the findings include that 3D printing molds is an approach that can alleviate shortages for skilled carpenters, reduce the cost and production time of elaborate molds, and decrease the cost of molds and overall production time in projects in which molds are used numerous times.

4. DOUBLE THERMAL PERFORMANCE

4.1 PRECAST INSULATED WALL PANELS WITH DOUBLE R-VALUE

Increasing the thermal performance of precast insulated wall panels typically comes with the penalty of having to also increase the thickness of the panel. However, as shown in Figure 1, the ability to reduce the thickness of the concrete wythes to 1.5" means that the amount of insulation can be doubled without making the panel thicker. Therefore, the new concrete mix and non-corroding inserts enabled lowering the weight of the panels by more than 50% as well as doubling the thermal performance of the panels.

4.2 SELF-HEALING SEALANT

Although precast concrete facades are extremely durable, one of their weak points are the sealants that are used at the joints between panels because they do not adhere well to dusty surfaces without a primer, do not adhere well to moist substrates, and develop cracks as they age. In buildings in which the precast panels and their sealed joints are key components of the air barrier system, failures in the sealant can lead to air leaks that increase energy use. To address these challenges, we developed a primer-less, self-healing sealant that absorbs contaminants that are on substrates (e.g., dust particles) so that the sealant can properly adhere to surfaces, adheres to moist substrates, and self-heals cracks as they develop in the sealant as well as accidental cuts. The technology consists of a composite that combines a self-healing polymer that was developed at ORNL (Figure 12) with a commercial sealant as described by Zhang et al. (2020) and in US patent application #17/117,827. Figure 13 illustrates how the composite recovered its tensile strength after it was cut into two and allowed to self-heal. The developed autonomous self-healing sealant received an R&D100 Award in 2021.

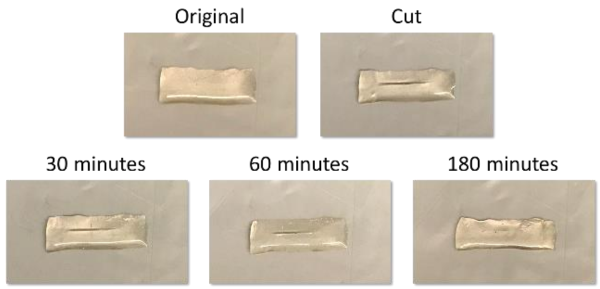


Figure 12. Self-healing polymer developed at ORNL.

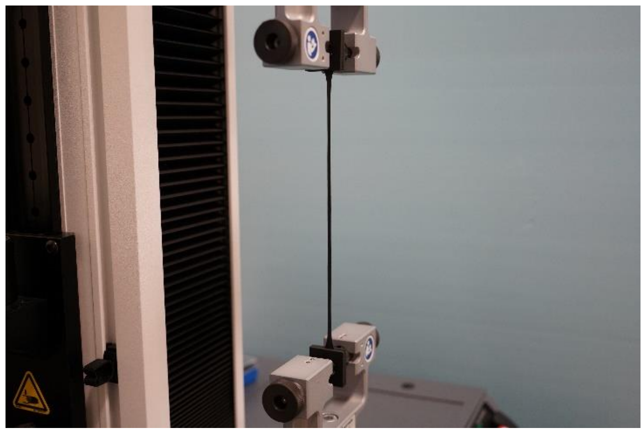


Figure 13. Demonstration of tensile strength recovery after composite made of a commercial silicone-based sealant and ORNL's self-healing polymer was cut into two and let self-heal.

5. CONCLUSION

The collaboration between ORNL, PCI, and the University of Tennessee yielded the following outputs:

1. A demonstration of the 3D printed molds in the One South First tower.

2. Designs for:
   a. Concrete mix for 1.5"-thick wythes
   b. Non-corroding erection lifting insert
   c. Non-corroding stripping lifting insert
   d. Concrete mix to turn casting beds twice per day
   e. 3D printed molds for precast concrete
   f. Self-healing sealant

3. One R&D100 Award for the Autonomous Self-Healing Sealant.

4. Two granted patents:
   a. Non-Corroding Stripping Lifting Inserts for Precast Insulated Panels. US patent #11,661,741 B2.
   b. High-Performance Concrete Mix for Precast Wythes. US patent #10,836,678,

5. One pending patent application:
    a. Self-Healing Adhesive Composition. US patent application #17/117,827.

6. Three journal publications and one in progress:
    a. Ghosh D, Abd-Elssamd A, Ma Z, Hun DE. 2021. Development of high-early-strength fiber-reinforced self-compacting concrete. Construction and Building Materials 226, 121051.
    b. Ghosh D, Ma Z, Hun DE. 2023. Effect of GGBFS slag on CSA-based ternary binder hydration, and concrete performance. Construction and Building Materials 386, 131554.
    c. Zhang Z, Ghezawi N, Li B, Ge S, Zhao S, Saito T, Hun DE, Cao PF. 2020. Autonomous Self-Healing Elastomers with Unprecedented Adhesion Force. Advanced Functional Materials 2006298.
    d. Hayes N, Hiremath N, Talley D, Gui Q, Hun DE, Sheriff S, Ma Z, Vaidya UK. Design and evaluation of novel composite face lifting inserts with interior threads for precast concrete sandwich panels. Submitted to Composite Structures. Under review.

These technologies enable the next generation of architectural precast insulated wall panels that are 50% lighter, 50% faster to produce, and/or have two times higher thermal performance.

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