Manufacture of full-scale geopolymer cement concrete components: A case study to highlight opportunities and challenges

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- Geopolymer cement is an alternative binder that is capable of forming concrete with competent mechanical performance and attractive environmental benefits.
- This paper presents a case study of the manufacture of full-scale geopolymer cement concrete components.
- This paper discusses mechanical characteristics of geopolymer cement concrete, quality of form finishes, strategies for curing, and challenges to full-scale production.

Innovators throughout the construction industry are making great strides toward increased environmental sustainability by updating processes, improving designs, and selecting greener materials. These aspects of modernization are both a response to demand from building owners and operators and a necessary means to remain competitive by achieving higher-performing buildings and infrastructure. Concrete producers have systematically improved the performance of their product by finding and exploiting benefits that are unique to concrete construction. These significant advances have included durable finishes, superior insulative properties in multiwythe wall components, economy with formwork, and rapid constructibility. The next frontier for the industry includes addressing the greenhouse-gas emissions associated with portland cement and further integrating the benefits of concrete materials into building functions and operations.

This paper describes the design and construction of a concrete house that was designed to accommodate a small family living in an urban environment. It is grid neutral with regard to energy production, meaning that it generates as much energy as it uses on an annual basis. The house was a 2013 entry into the U.S. Department of Energy's Solar Decathlon.[1] This biennial event engages 20 teams from universities around the world to design, build, and operate solar-powered housing. Entries are judged on energy performance, architecture, innovation, and economy.

The application of concrete in the building design was a significant technical accomplishment due to the use of an integrated thermal mass system—a hydronic heating and cooling system in the interior wythe of the wall panels—as well as its use of geopolymer cement as the concrete binder. Although the concrete walls provide an impressive architectural effect (**Fig. 1**), they are also a central component of the building energy system. In addition, they enable greater overall material, energy, and construction efficiencies. The design team chose a concrete construction system to provide overall building efficiency through continuous insulation and thermal mass. Geopolymer cement concrete was used to reduce the carbon dioxide (CO_2) emissions and energy intensiveness of the concrete construction. The concrete components of the structure include floor plates cast integrally with grade beams and structural insulated wall panels. This flatwork was fabricated into four pods for transportation and ease of final assembly.

Geopolymer cements

Geopolymer cements are formed by dissolving aluminosilicate material in a strong alkaline solution. The resulting paste can be mixed with aggregates and cured to form concrete with strength and elastic characteristics similar to those of portland cement concrete. Often the aluminosilicate material of choice is fly ash, a byproduct of coal combustion. Because geopolymer cement concrete curing does not rely on hydration reactions, it is particularly attractive for prestressed concrete construction for its rapid strength development and reduced tendency for shrinkage and creep compared with portland cement concrete.

Because of its use of recycled materials and its independence from the CO_2 emissions associated with portland cement manufacture, geopolymer cement concrete promises to become an environmentally favorable material for construction. Most advocates of geopolymers in construction have focused on the avoidance of CO_2 emissions due to combustion and to limestone calcination in portland cement manufacture. Critical carbon footprint analyses of geopolymer and portland cements have estimated the reduction in CO_2 associated with geopolymer cement to range from as high as 80%[2] to as low as 9%.[3] The significant energy inputs that are unique to geopolymer cement are due to elevated-temperature curing and the production of activating chemicals that are necessary to develop its cementitious properties. However, unlike portland cement concrete, geopolymer cement concrete presents the possibility of reducing CO_2 emissions using current technology, for example by using waste heat for curing or manufacturing activating chemicals with energy from renewable or CO_2-neutral sources.

Figure 1. Precast geopolymer cement concrete house.

Despite the great promise shown by geopolymer cement concrete through laboratory research,[4–6] there are few examples of full-scale production. Several sources have reported that flexural performance of reinforced geopolymer cement concrete beams closely resembles that of similarly reinforced portland cement concrete beams.[7–10] Columns of geopolymer cement concrete have also been investigated and show such similar performance to portland cement concrete as to warrant the use of existing design strategies and code provisions.[11–13]

Because geopolymer cement concrete requires much of the same handling, mixing, and placement equipment as portland cement concrete, producing geopolymer cement concrete in a typical precasting facility is feasible. However, some of the unique characteristics of geopolymer cement concrete would necessitate changes in the process before scaling up production from bench scale to plant scale. The experience of manufacturing the precast concrete insulated panels for the concrete house is presented here as a case study of full-scale production in a plant. First, a description of the geopolymerization process is presented to compare the material with portland cement concrete. After this introduction, the specifics of producing the panels for the concrete house are presented along with suggestions for future research and development.

Geopolymerization

When fly ash is introduced to concrete that contains portland cement, the mixture develops strength through a series of hydration reactions through which calcium silicate hydrate forms. Contact between portland cement grains and water initiates the reactions. Unlike portland cement hydration, geopolymerization may be described as a three-phase process that is initiated by contact between an aluminosilicate material (such as fly ash) and an activating solution with high pH. These phases include dissolution, reorientation, and hardening.

Dissolution

The aluminosilicate material is mixed with an alkaline activating solution that releases silica and alumina monomers. The degree to which the aluminosilicate material dissolves is related to the reactivity of the material, the strength of the activating solution, and time.[14,15] Activating solutions are typically a combination of an alkaline soda, such as sodium hydroxide or potassium hydroxide, and a soluble silica, such as sodium silicate. The proportions of these solutions vary and are rarely reported due to their proprietary nature. However, the concentration of effective solutions typically ranges from approximately 1.7 to 3.3 lb (5 to 10 N) sodium hydroxide per gallon of solution.

Reorientation

The alumina and silica monomers begin to reorganize and condense into larger groups. As the groups form, water molecules are released. The dissolution phase and the alkalinity of the activating solution greatly affect the rate of reaction.

Hardening

The reorientation phase results in a continuous polymeric network of three-dimensional aluminosilicate structures. The mass may harden slightly on its own depending on the makeup of the source materials and the ambient conditions. However, to gain significant strength, the material must be cured with heat. A variety of temperatures has been investigated with a trend of increasing temperatures (up to 212˚F [100˚C]) that lead to accelerated hardening and strength gain.[16] Temperatures below 140˚F (60˚C) have generally been found to result in unsuitably slow reactions when unmodified source materials are used.[17]

The dissolution and reorientation phases overlap to some degree. Initiation of hardening tends to preclude further transport of geopolymer precursors and causes an end to these phases. Hardening may be initiated autogenously through a drop in pH,[18] or availability of nucleation sites caused by the presence of calcium or iron in the mixture.[19] The external application of heat also triggers hardening. Dissolution and reorientation periods of more than 48 hours seem to provide few improvements in material performance.[20] On completion of hardening, the material typically exhibits at least 80% of its ultimate compressive strength.

Integrated wall system

The concrete house walls were designed to function as a hybrid—a blend of passive and active—a high-thermal-mass, radiant heating and cooling system. Passive high-thermal-mass systems include interior masonry and concrete partitions and exterior masonry and concrete walls with the insulation located on the exterior surface. These systems moderate diurnal temperature variations around the thermostat set point temperature for the space they enclose. Active high-thermal-mass systems include air loop rock storage bins and water loop heat storage tanks. These systems act as heat sources for on-demand heating and heat sinks for cooling.

The hybrid system developed provides both moderation of diurnal temperature variations and predictive on-demand heating or cooling. This is accomplished through the use of a continuously insulated architectural precast concrete sandwich panel with a 6 in. (150 mm) thick interior wythe containing a modified capillary tube hydronic system. The wythe functions as a passive, high-thermal-mass system to moderate diurnal temperature variations. The capillary tube hydronic system is modified from its typical application, which locates the tubes near the surface facing the conditioned space for on-demand heating or cooling. By locating the tubes away from the surface enclosing the conditioned space, thermal lag can be used to charge the wall for anticipated heating and cooling demands. This storage feature allows a more-gradual accumulation of heat via solar collectors or dispersal of heat via rooftop cooling ponds.

Figure 2 depicts some of the important subsystems. The network of cross-linked high-density polyethylene tubes carries hot water for curing the panel. The polyethylene tubing was added to the wall design as a workaround when trials using a low-temperature hot-air curing chamber yielded unsatisfactory results. The capillary tube system could not be used to cure the interior wythe because the type that was already on-site was made from polypropylene random copolymer with a maximum operating temperature below the needed water temperature for curing. For future panels, a polypropylene random copolymer capillary tube system with a higher allowable operating temperature should be used for curing. During building operation, the capillary tubes, not the polyethylene tubes, will constitute the radiator section of the hydronic heating and cooling system.

Production

Mixture proportioning development

The concrete mixture was developed prior to forwarding the architectural design to the structural engineer. At present, there is not a standard methodology for geopolymer cement concrete mixture proportioning. Each fly ash has its own reactivity that must be evaluated to ensure the performance of the resulting concrete mixture. The provisions of ASTM C618[21] for Class F fly ash give a good indication of potential reactivity and are frequently used to screen potential ash sources. Because the intended concrete mixture did not have a long track record of performance, 15 individual batches were produced (**Table 1**). In the early stages of mixture design development, several

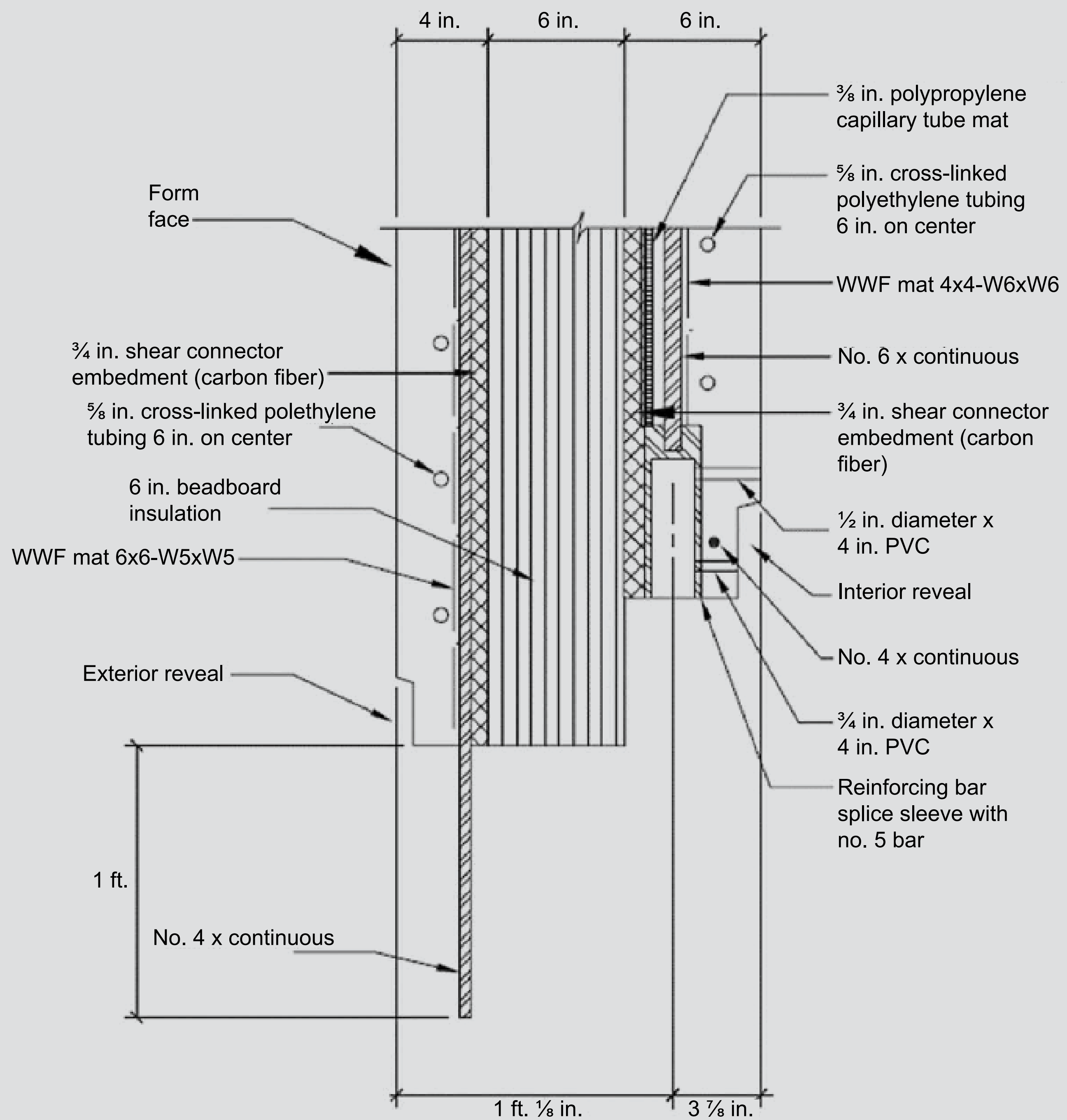

Figure 2. Typical cross section of the precast concrete structural insulated panel. Note: PVC = polyvinyl chloride; WWF = welded-wire fabric, which is also known as welded-wire reinforcement. No. 4 = 13M; no. 6 = 19M; 1 in. = 25.4 mm; 1 ft = 0.305 m.,

aggregate sources were attempted to preview the effect they would have on concrete color and final appearance after sandblasting. A ⅜ in. (10 mm) granite aggregate was selected for the project, and the batches are listed in Table 1. Although the batches had identical mixture proportions, many replicates were produced to assess repeatability as well as to provide materials for the design team to explore finishes and colors. Three 3 × 6 in. (75 × 150 mm) cylinders were prepared from each batch. The cylinders were subjected to the same curing routine that was planned for the full-scale precast concrete panels, which consisted of 24 hours of aging at ambient temperatures and 48 hours of curing at 167°F (75°C). ASTM C39[22] procedures were used to test the cylinders in triplicate after 3 days, immediately following removal from the high-temperature curing chamber. **Table 2** presents average compressive strength results of the 15 consecutive batches. Variations in the strength are results of small differences in batching procedures, aggregate moisture content, and other factors that would be difficult to closely control in plant settings.

Table 1. Geopolymer cement concrete mixture proportions

Material	Sodium silicate	Sodium hydroxide	Class F fly ash	Fine aggregate	Course aggregate	Water	Total
Weight, lb/yd^3	277	36	787	1370	1370	75	3915

Note: 1 lb/yd^3 = 0.593 kg/m^3.

ACI 318-11 provides a process for setting the design strength of concrete mixtures based on compressive strength test results of portland cement concretes.[23] Although further research may justify adapting this method for use with geopolymer materials, it was used as described in this application. The intent of the procedure is to ensure that the probability of obtaining compressive strength results below the design target is less than 1%. The mean strength and standard deviation of the data presented in Table 2 are 5250 and 355 psi (36.2 and 2.45 MPa), respectively. ACI 318-11 Table 5.3.1.2 provides a modification factor of 1.16 for the standard deviation of data sets based on 15 tests.[23] Due to the requirements outlined in ACI 318-11 Table 5.3.2.1, a safe design strength of 4800 psi (33 MPa) for the geopolymer cement concrete mixture was developed for the project.[23]

Table 2. Geopolymer cement concrete compressive strength based on the average of three 3 × 6 in. cylinders tested with ASTM C39 procedures

Test number	Compressive strength, psi
1	5930
2	5210
3	5210
4	5110
5	4810
6	5150
7	5150
8	5570
9	5720
10	5130
11	5650
12	5410
13	4890
14	4610
15	5270

Note: 1 in. = 25.4 mm; 1 psi = 6.895 kPa.

Production process

Due to the conditions (such as elevated-temperature curing) that are necessary for formation of geopolymers, accommodations must be made in production. The predominant considerations discovered while producing the concrete panels included heating methods suitable for large concrete castings and finishing techniques that work for geopolymer cement concrete. These and other considerations are described in the following sections.

Requirement for heating

Geopolymer cement concrete requires heat to gain strength. Within a precasting facility, heat is sometimes used to accelerate curing in portland cement concrete. However, because portland cement hydration is exothermic and does not require much heat, the output of these systems may be insufficient to reach target temperatures for curing geopolymer cement concrete. Geopolymer concrete cement is often cured within the range of 140 to 170°F (60 to 77°C). Insulating the formwork and top face of the concrete slab and using the hydronic tubes embedded in the wall panels to circulate heated water enabled the concrete to reach the desired temperatures. Most heated formwork is made of steel, which reacts with the fresh geopolymer unless the release agent is able to isolate the two materials.

The hydronic tubes consisted of ½ in. (13 mm) inside diameter polyethylene attached to a mat of welded-wire reinforcement (**Fig. 3**). The mat was selected so that the spacing of the tubes could be maintained at 6 in. (150 mm) on center for even distribution of heat throughout the concrete. A tank boiler with an electronic thermostat and pump system heated water passed through tubes (**Fig. 4**).

A network of temperature sensors was embedded in the concrete to monitor temperatures during curing. The sensors were distributed at locations that represented several depths, proximity to edges, and proximity to heating tubes. **Figure 5** presents the logged results of several of these sensors. The curing requirements determined during mixture proportioning indicated that 24 hours at the target temperature was sufficient to develop the design strength. The 12 kW boiler heated the panels containing 11.8 yd^3 (9.03 m^3) of geopolymer cement concrete from 76 to 170°F (24 to 77°C) in approximately 35 hours. The boiler maintained the target temperature for a total of 35 hours before the system was shut down and the concrete began cooling.

Figure 3. Red cross-linked high-density polyethylene tubes and blue capillary tubes for concrete curing and building climate control are tied to reinforcing steel before placing concrete.

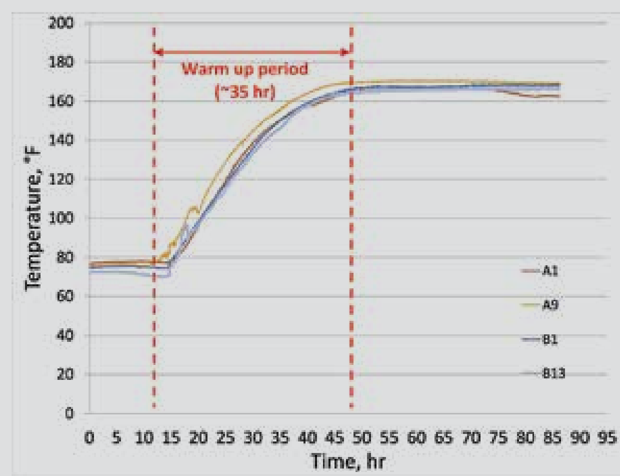

Figure 5. Temperature of panels during the heated curing process. Note: °C = (°F – 32)/1.8.

The extra time beyond 24 hours was added as a precaution to ensure that all areas reached the target temperature. Because the sensors continue to function after curing, they have been incorporated into the building monitoring and control system.

Consistency of color

The ability to accurately reproduce colors is exceedingly important in architectural precast concrete. While gray cement varies in its tint, the availability of white cements allows precast concrete producers to use colorants to consistently match colors between batches. The color of geopolymer cement concrete is a function of the color of the fly ash, which can vary from dark gray to light pink, depending on the source. It is not unusual for fly ash from the same source to vary because its composition is affected by the combustion parameters at the power plant where it is produced.

A scientific method for adjusting color and repeating tints from batch to batch was not developed, but commercially available colorants worked well. These colorants included earth oxides for yellows and reds and titanium dioxide for light gray. Light gray was selected, and it was used at a variety of doses without affecting the properties of the fresh or cured geopolymer cement concrete.

Figure 4. Heating equipment for curing includes two boiler units connected to a circulator pump and manifold for equalizing flow rates through multiple concrete volumes.

Source materials

Changing emissions-control devices and coal markets affect the availability of fly ash. Class F fly ashes are typically suitable for geopolymer cement concrete. However, some variation in fly ash characteristics that do not significantly affect its use in portland cement concrete can have detrimental effects in geopolymer cement concrete. Factors such as the age, amorphous fraction, elemental composition, particle size, and carbon content of the fly ash all have significant effects on the characteristics of geopolymer cement concrete.[24] Although the relationships between these fly ash characteristics and the mechanical performance of the cured geopolymer cement concrete are generally understood, there is not yet a process of rapidly adapting activating solutions or curing regimens to differences in the fly ash. The process of adjusting geopolymer cement concrete mixture proportions for new source materials is much the same as developing mixture proportions for portland cement concrete. Prior to casting the large panels, the team identified a source of Class F fly ash near the project site. Mixture proportions were tested and adjusted specifically for this source.

Formwork and concreting equipment

A strong priority during this experimental program was to minimize the need for specialized equipment. The mechanical performance of most existing concreting equipment is adequate for geopolymer cement concrete. However, the following peculiarities were noted.

Figure 6. Batching activating solutions into the concrete mixing truck.

Mixers

The geopolymer cement concrete was mixed in a 10 yd^3 (8 m^3) rotary drum truck. The aggregate, fly ash, and water were measured and added to the truck at a batch plant (**Fig. 6**). Immediately before mixing, activator solution was added directly to the truck through the charge hopper. Trial and error had shown that 150 revolutions of the drum at high speed were sufficient to mix a truckful.

Formwork and finish

The team experimented with many form-making materials that would be durable through several uses and nonreactive with the geopolymer while providing a suitable surface texture for the panels. Steel formwork was used initially but required thick form-release agents to prevent interaction with the geopolymer cement concrete. Lighter form oils saponified on contact with the alkalis in the geopolymer cement concrete. Because iron can provide nucleation points for the formation of the geopolymer, excessive bonding between the geopolymer cement concrete and the formwork occurred during curing. Large spalls often resulted when the forms were stripped. Polyethylene formliners worked well, were durable, and imparted a smooth finish to the geopolymer cement concrete. To produce the surface pattern selected, plywood painted with a thick wood sealer was used. This coating was resistant to the alkalinity in the geopolymer cement concrete.

Although the concrete cast against the formwork picks up fine detail and reflects the smoothness of the surface, the float-finished side does not maintain an acceptable finish. At the plant, these sides were finished with a bull float. However, after construction, they were finished with a vinyl-based joint compound specifically manufactured for skim coating concrete.

Interaction with portland cement concrete

One potential challenge for production of geopolymer cement concrete in a plant that also produces portland cement concrete is that the materials cannot tolerate intermixing. Calcium-rich portland cement concrete causes rapid setting and potential unsoundness in geopolymer cement concrete. Therefore, mixers must be cleaned more thoroughly before switching between geopolymer cement concrete and portland cement concrete than would be necessary between batches of portland cement concrete.

Placement and consolidation

After mixing, the concrete was transferred to a bucket and dropped into the formwork (**Fig. 7**). The consistency of geopolymer cement concrete is difficult to describe in terms of slump or spread. Although it is essentially self-consolidating, it is also thixotropic and can be stiff and gummy when being coaxed to flow quickly. However, in time it continues to flow by gravity until it forms a level surface. Geopolymer cement concrete responds well to vibration and immediately flows into corners and around obstructions. The table-mounted vibrators at the plant were ideal for consolidating the concrete.

Moisture control

Prior research has indicated that the water-cement ratio has the same effect on the strength of geopolymer cement concrete as portland cement concrete.[20] A high-range water-reducing admixture was used to reduce the amount of water required to achieve the necessary workability. However, unlike portland cement concrete, which requires a relatively large amount of water to hydrate the cement, geopolymer cement concrete has a fairly small chemical demand for water. The mixture required only 75 lb/yd^3 (44 kg/m^3) of water (Table 1). The excess moisture in the aggregates may suffice or could even be too much for the geopolymer cement concrete. Because the sodium silicate activator is in liquid form, it adds to the workability of the concrete in a similar fashion as would more water.

Results

The precast geopolymer cement concrete structure was completed in approximately two weeks and was assembled into three pods that were shipped from North Carolina to the competition site in California.

Compressive strength of panels

As was found with the trial batches prepared before casting the panels, the compressive strength results varied significantly from batch to batch. The full set of panels was prepared from five batches of truck-mixed concrete.

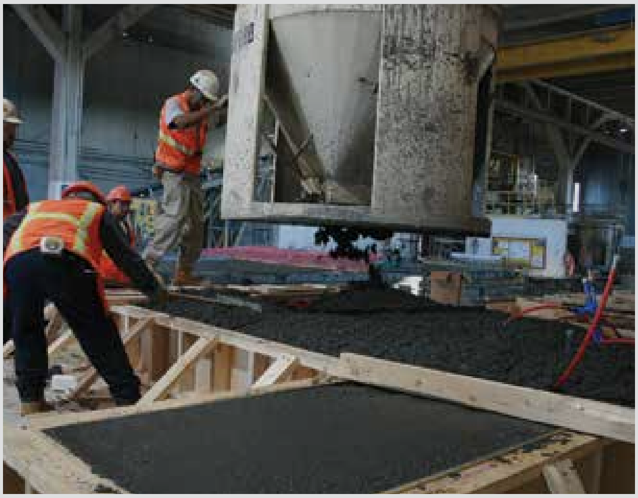

Figure 7. Placing concrete in forms.

The 28-day compressive strength of these batches based on the average of three 4 × 8 in. (100 × 200 mm) cylinders was 8650, 6480, 4410, 4920, and 5960 psi (59.6, 44.7, 30.4, 33.9, and 41.1 MPa). Thus, the average compressive strength was 6080 psi (41.9 MPa), which is higher than the trial batches, but the standard deviation was also greater. For the laboratory batches, the standard deviation of 15 trials was 355 psi (2.45 MPa), whereas the five production batches yielded a standard deviation of 1650 psi (11.4 MPa). The greater variability in production may have been related to the addition of water at the plant or to the time between mixing and placing some of the batches. Only one batch fell below the design strength of 4800 psi (33.1 MPa) but was deemed to be adequate by the structural engineer of record.

Material costs

The costs related to materials in geopolymer cement concrete were tracked during the production of the Solar Decathlon entry and are reported in **Table 3**. The cost of geopolymer cement concrete is more than three times that of an equivalent strength of portland cement concrete. The bulk of the volume in either concrete mixture is occupied by aggregates, and costs associated with the aggregate fraction of the concrete are substantially similar. The cementitious portion of the volume for geopolymer cement concrete is composed of fly ash, sodium silicate, and sodium hydroxide. Although fly ash itself is often inexpensive, the addition of the activating chemicals makes the geopolymer cement materials significantly more expensive than portland cement. Thus, the cost of geopolymer cement concrete was \$160.83/yd^3 (\$210.36/m^3) compared with \$50.88/yd^3 (\$66.55/m^3) for portland cement concrete.

Additional costs for heat curing are also associated with geopolymer cement concrete. The difference in costs among the various fuels that are used to power hot-water boilers or steam generators are large, so this cost is not reported. However, the energy requirement to heat the 11.8 yd^3 (9.02 m^3) of material from room temperature to curing temperature was found to be approximately 420 kWh. The national average cost at the time of casting was \$0.067/kWh.[25] At typical industrial electricity rates, the cost was \$2.49/yd^3 (\$3.26/m^3).

The high cost of geopolymer cement concrete at present should not be taken as a deterrent to further investigation. One reliable aspect of all commercialization processes is the aggressive search for cost-reducing opportunities. The materials used in this prototype were of a higher grade than would be necessary for construction. For instance, due to local availability, the purity of the sodium silicate and sodium hydroxide was sufficient for much more exacting processes, such as use with foods, detergents, or other consumables. Both materials can be synthesized or extracted from waste-stream materials in a form that is adequate for construction.

Table 3. Cost of constituent materials in geopolymer cement concrete and portland cement concrete

Material	Cost per 100 lb	Geopolymer cement concrete, lb	Cost for 1 yd^3 geopolymer cement concrete	Portland cement concrete, lb	Cost for 1 yd^3 precast portland cement concrete
Sodium silicate	\$42.00	277	\$116.34	0	\$0
Sodium hydroxide	\$64.00	36	\$23.04	0	\$0
Fly ash	\$1.13	787	\$8.92	0	\$0
Fine aggregate	\$0.42	1370	\$5.79	1250	\$5.28
Coarse aggregate	\$0.49	1370	\$6.73	1800	\$8.84
Water	\$0.02	75	\$0.02	260	\$0.06
Portland cement	\$5.64	0	\$0	650	\$36.69
Total	n/a	3915	\$160.83	3960	\$50.88

Note: n/a = not applicable. 1 lb = 0.454 kg; 1 yd^3 = 0.765 m^3.

Competition performance

The 20 teams that competed in the 2013 U.S. Department of Energy's Solar Decathlon were evaluated in a series of five juried (architecture, market appeal, engineering, communications, and affordability) and five measured (comfort, appliances, home life, commuting, and energy balance) criteria. The concrete house described in this paper finished thirteenth overall. The precast concrete wall system contributed to a tie for third place in engineering. The concrete house also received first place in the People's Choice award, which is based on the public's votes for its favorite entry.

Areas of additional required research

Although this was a successful experience with prototyping a novel construction method, the difficulties encountered indicate several areas of required research that can help inform a potential guideline and best practice for geopolymer cement concrete.

Sensitivity analysis

During production, many factors affect the characteristics of the concrete. These factors may include working temperature, the addition of water for workability, and the actual temperature achieved during curing. The variability in the compressive strength results of concrete produced at the plant was much greater than in the laboratory. This would also be expected of portland cement concrete. However, the variability in the production-scale mixtures would not be acceptable for normal production. The most critical sensitivity analyses would seem to relate to water-cement ratio, curing temperature, and curing time because these variables are the most likely to be altered during production. The effects of changes in these conditions on the strength and durability of geopolymer cement concrete must be established. Conservatism was used when making decisions about matters that might affect the quality of the concrete. In normal production, a set of construction tolerances is necessary to inform quality-control managers of the suitable ranges of batching, mixing, and curing conditions that result in acceptable quality.

Workability enhancers

Neither slump nor spread appears to be a good measure of geopolymer cement concrete consistency. Although geopolymer cement concrete is similar to self-consolidating concrete in some ways, it is significantly more viscous than portland cement concrete. This characteristic led to frustration on the part of finishers, who were not able to use their normal tools to achieve typical results. A greater understanding of the ways that high-range water-reducing admixtures and water-reducing admixtures affect the workability of geopolymer cement concrete could improve its finishability.

Finishing and patching

Because of the curing requirements for geopolymers, it is not easy to make small batches of material for filling bugholes, pop-outs, and other common aesthetic defects. A range of suitable materials that are compatible with geopolymer cement concrete, durable, color matchable, and self-curing must be established.

Applicability of existing quality-control measures

Existing quality-control measures for portland cement concrete provide a good starting point. However, there is not a body of evidence that indicates the suitability of tests, such as air content by ASTM C231,[26] for geopolymer cement concrete. Furthermore, due to the effect of curing temperature on the ultimate strength and quality of the concrete, a handling and heating strategy for small test cylinders that mimics the thermal condition of concrete elements is necessary. As part of the preparation for this project, cores were removed from a slab and compared for strength with that of companion cylinders cast at the same time. The cores from the slab were found to have significantly higher compressive strength in all cases—possibly due to the much longer cool-down period. Nonetheless, an accurate method is required for using companion cylinders to estimate compressive strength of the component.

Conclusion

This case study describes the first example of total architectural precast geopolymer cement concrete construction of a habitable building. The building succeeded in the areas of energy performance, architecture, innovation, and public opinion. A significant outcome of this experience was the ability to identify areas of future research and development that will be necessary to enable more mainstream applications of geopolymers in construction.

The factory environment of precasting facilities is uniquely suited for the production of geopolymers due to the availability of heating devices for curing and tight process control. Geopolymers could provide a niche for precasters to offer concrete with significantly reduced CO_2 emissions. The broad similarity in characteristics of geopolymer cement concrete and portland cement concrete for mixing, placing, component design, appearance, and long-term performance suggests that the gradual adoption of the material would seem more familiar than disruptive. Currently, the significant impediment to expanding use of geopolymer binders in concrete is the availability of a uniform fly ash source material as well as specifications similar to ASTM C618[21] that can be used to characterize ash specifically for geopolymers. Recent guidance from the U.S. Environmental Protection Agency has encouraged the beneficial reuse of coal ash.[27,28] This guidance, combined with the availability of improved reprocessing technologies and the desire for more-sustainable products, will likely stimulate fly ash suppliers to provide the necessary materials for geopolymers.

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Abstract

Geopolymer cement is an alternative binder that is capable of forming concrete with competent mechanical performance and attractive environmental benefits. Carbon dioxide emissions from geopolymer cement concrete are low compared with portland cement concrete, and the binder incorporates high volumes of the recycled material fly ash. The typical strength of the resulting materials ranges from 4000 to 10,000 psi (28 to 69 MPa) depending on mixture proportions, aggregates, and curing. Additional beneficial features to precast concrete production include rapid strength gain and low requirements for plant infrastructure beyond typical concreting equipment. This paper presents a case study of the manufacture of full-scale geopolymer cement concrete components. Mechanical characteristics of geopolymer cement concrete produced at the plant, quality of form finishes, and strategies for curing are described. Challenges to full-scale production, as identified by plant personnel and the research team, are also presented.

Keywords

Alternative binder, geopolymer, insulated panel, sustainability.

Review policy

This paper was reviewed in accordance with the Precast/Prestressed Concrete Institute's peer-review process.

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