2008 Prague

The use of a continuous mixer and a fast-setting cement to produce GFRC architectural products

Hiram Ball, Jr

Biography: Hiram Ball, Jr is President of Ball Consulting Ltd located in Ambridge, PA. He is a graduate of Franklin and Marshall College. He is a member of ACI 549, ASTM C-11 and C-27, and the GFRC committee of the Prestressed/Precast Concrete Institute. He has been involved in GFRC and other thin-sectioned inorganic composites for 30 years, with a special focus on durability.

Summary

Typical demolding times of glassfiber-reinforced concrete (GFRC) cast parts are typically 16 h. This has limited the acceptance of GFRC, or any cement-based product, into products requiring high-volume production because of the high costs of multiple moulds associated with a material chemistry having such long demolding times. This paper discusses a unique system utilizing Portland type I cement, a fast-setting cement, and specially designed mixing equipment to process the material so that demolding times in the 1–2 h range are possible. A conventional weight formula (128 pcf) and a lightweight formula (71 pcf) are available. For convenience, the formulas are supplied pre-blended.

Keywords: fast-setting cement; glassfiber-reinforce concrete; rapid demolding

Introduction

Glassfiber-reinforced concrete (GFRC) has typically been produced using the spray chop, sprayed premix or vibration cast methods. In the spray chop or sprayed premix methods the mix components of Portland cement, sand, polymer, water, pigment and plasticizer are mixed into slurry using high-shear mixers. The slurry is transported to either a rotor/stator pump or a peristaltic pump to be sprayed into the mold. For vibration casting the mix components can be mixed in a conventional mortar or pan mixer prior to being transported to the molds for casting.

In either case, the slurry typically has 20–25 min. of working time once it is mixed to be transported, placed and compacted before it loses workability and starts to gel. Once cast or sprayed, the GFRC requires 16 h, or overnight at temperatures ≥ 62°F to develop demolding strengths.

GFRC in the USA has typically been used as the material of choice for custom-designed architectural panels and ornamentation that have unique shapes and finishes and that can justify the costs of getting only one part per production day out of a mold.

GFRC, and essentially all cement-based products, have been denied access to many high-volume, custom or standard markets due to this long curing time requirement. The cost of making enough molds to increase production of parts would be prohibitive for many projects.

To attempt to resolve this problem, the use of a fast-setting cement called Qwix® was introduced to the spray-up and cast premix markets several years ago. Qwix® is a calcium sulfo-aluminate cement chemistry that is used in conjunction with Portland type I cement in various ratios to achieve a range of set and demolding times. Qwix® is not a stand-alone product. It **must** be used as a blend with Portland type I cement. Qwix® blended with Portland type I has been tested to prove its stability and durability in exterior conditions.

Research significance

The importance of this development is that there is now a family of Portland cement-based material systems and processing equipment to cast parts with set and demolding times comparable to organic resin systems, but without the environmental issues associated with resin systems.

Material chemistry

Qwix® is a specific calcium sulfo-aluminate (C4A3S) formula, rich in crystals, made in a kiln by Buzzi Unicem USA Inc. It contains no chloride component, therefore it has none of the problems associated with chlorides. It has minimal shrinkage and is not subject to regression. It is considered sulfate resistant since all C3A hydration takes place in the plastic stage. Qwix® is considered a hydraulic cement material per ASTM C 219.

SiO_2	10–12%
AL_2O_3	24–26%
Fe_2O_3	3–4%
CaO	42–45%
MgO	0.5–1.0%
SO_3	20–23%
K_2O	0.2–0.3%
Na_2O	0.2–0.3%

Qwix® klinker from the kiln is ground into a light grey/beige powder that is ready to be blended with either Portland type I grey or white cement in specific ratios to achieve the desired demolding time.

Portland to CSA	Set time	3 h (psi)	24 h (psi)	28 days (psi)
80/20	45 min	1,740	2,500	6,470
70/30	40 min	2,670	6,080	6,970
60/40	35 min	3,450	4,500	7,450
50/50	30 min	4,150	5,870	9,250

The chart above gives an indication of typical set times and compressive strength development at 3 hs, 24 h and 28 days for the ratios of Portland to Qwix® shown using a typical Portland type I grey cement. These values will vary slightly depending on the specific cement used. These values are also dependent on the temperature of the mix water, the water/cement (w/c) ratio, the type of plasticizer used, the ambient temperature and whether or not the cast parts are covered with plastic. These results were obtained from mixes not containing alkali-resistant (AR-)fiber or Forton VF-774 polymer.

Additional third-party testing with mixes containing 6% polymer solids of Forton VF-774 to the weight of cement and 1.5% Cem-FIL AR-fiber and a 70 Portland to 30 Qwix® ratio indicates a 28-day compressive strength of 9,400 psi with minimal shrinkage. For practical processing, curing and demolding properties, the typical ratios are 70/30, 80/20 and 85/15.

To give an example of expected working time for the product, using 54°F mix water in a 65°F ambient plant temperature, a mixing time of 5 min. and working time of 20 min. is possible before losing workability with a 70/30 ratio mix and 6% polymer solids of Forton VF-774 to weight of total cement.

It has been determined by plant testing that the sooner the material in the mould reaches 82°F, the faster and more thorough the cure, resulting in a stronger demolded part in shorter time. This temperature is easily achieved by simply laying a piece of plastic sheeting over the back of the piece to hold in the exothermal heat.

This information and the mix design formulas were given to potential GFRC and precast producers along with the Qwix® supplied in bags or super sacks. These approaches met with limited sales success because it was one more thing for the mixer man to measure and control. It was one more product for the plant to stock and make sure was in inventory and most producers did not use enough of it to gain any purchasing economies. The most important issue was that conventional mixing equipment and plant practice did not allow for the higher Qwix® ratios required to give 1–2 h setting times due to the shorter working time of the mix and the potential of it setting up in the equipment.

Resolution of production issues

A new approach to mixing and casting was required to obtain the benefits of the rapid demolding times of the mixes with higher ratios of Qwix® to Portland cement. The earlier plant experience determined that a procedure was required that mixed the components very quickly, with minimum energy or heat imparted to the slurry and also that very thoroughly dispersed all the powders, pigments and polymer to give a lump-free matrix with minimal entrapped air prior to casting. If fiber was added, the process must not abrade the AR-fiber that was being added. A method of uniformly including pigments and Forton polymer was also required. It was also important to keep the equipment investment as low as possible to make it affordable for the small to medium producer.

A continuous mixer of European design was obtained and a 60/40 dry blend containing 1.5% of a ½ in. (12 mm) high strand integrity AR-fiber was blended to use as a test to determine if there would be any build-up of mixed material in the mixer housing, working on the theory that this was the worst-case ratio that would be used. The test was successfully completed with no mix or fiber build-up in the mix tube. Using this process a 30 min. demolding time was achieved. Water, polymer and plasticizer were pumped into the mixer tube via a diaphragm pump with a flow meter to control the w/c ratio. The mixing tube was essentially self-purging as the freshly mixed material moved through it. The test was very successful, but quickly raised two issues to be dealt with. The first issue was that the existing continuous mixers did not have the proper controls to maintain color uniformity and the second issue was the volume of slurry output. The continuous mixer used for the test had an output of 130 pounds of slurry mix – per minute.

The color control issue was resolved by having a tank that contained water, VF-774, plasticizer and liquid pigments kept under mild agitation in ratio to the dry blend. This liquid was pumped to the liquid intake port on the mix tube under constant pressure, thus insuring no pulsation and eliminating any liquid to dry blend variation.

The newly designed continuous mixer met our requirements of keeping the cost under $18,000, but at this rate of consumption it would require the producer to invest in silos and high-speed mixers to make the blend.

A new product line was developed

To satisfy potential users of the continuous mixer that could utilize the higher Portland/Qwix® ratios, the Fast Stone® cement line of products was brought to the market. This enabled producers to benefit from the low investment cost of the continuous mixer, high throughput of a properly formulated mix and short demolding times. Formulas were developed and tested for specific customer requirements as well as formulas that would satisfy the general market's needs. In order to meet specific market and product needs, formulations were developed using several ratios of Portland cement (white or grey) to Qwix®. Those formulations also may include some or all of the following: sand, recycled glass beads, pigments, pozzolans and AR-glassfibers. Typical Fast Stone® formulas can be demolded in 1–2 h.

Since shipping costs have become such a major component of any sourcing analysis, toll blenders for the Fast Stone® products were evaluated and chosen on a regional basis to minimize shipping costs to the final user.

Typical properties of Fast Stone® and Fast Stone LT® are shown in the following charts.

Fast Stone
Cement®
0.5 - 2.0% 12mm AR
28 days

Dry Density	115 - 130 pcf
Compressive Strength	7,000 - 9,400 psi
Flexural Yield	1,100 - 1,700 psi
Flexural Ultimate	1,300 - 1,700 psi

Fast Stone LT®
0.5 - 2.0% 12mm AR
28 days

Dry Density	64 - 75 pcf
Compressive Strength	2,600 - 3,700 psi
Flexural Yield	530 - 890 psi
Flexural Ultimate	550 - 890 psi
Thermal Conductivity	K factor 2.052

The astute observer will note that in some cases the flexural yield (FY) equals the flexural ultimate (FU), indicating a brittle break under load when tested to ASTM C 947[2]. This is correct and to be expected when using such small amounts of the 100-filament fiber that was used in the test. Examination of the fracture interface indicated there was fiber pullout, but there was not enough to show a difference between FY and FU. However, testing indicated an increase in FY for the same basic mix design as fiber loadings increased from 0.5% to 1.5% of total weight of mix. So the fiber made a contribution to the cured matrix strengths. Higher concentrations of 200-filament fiber and longer fibers show the flexural properties that are seen in typical GFRC premix composites when tested to ASTM C 947.

We have determined that 1.5% of total weight of mix of a ½ in. (1 mm) high strand integrity fiber is the maximum that can be successfully dry blended and bagged. If a producer was making their own dry blend and not bagging it or the product was going directly to a super sack, higher amounts and longer high-strand-integrity fibers could be used because the continuous mixer can process the blend without the fibers clumping or abrading.

Plant and processing

Part size and the specific Fast Stone® formula will determine the size and orientation of the production space to accommodate a logical flow of materials to the continuous mixer and filled molds moved to a curing space. Typically, a roller conveyor system is under the discharge outlet on the continuous mixer so that freshly mixed material drops directly into the mould in order to maximize the working time of the higher ratio mixes. Small air-operated vibrators are attached to the side rails so that the mix is vibrated at low amplitude while the mold is being filled. Empty molds are fed to this point for an operator to fill. After filling, they are pushed along for additional vibration (if needed), screeding, placement of embeds and any other finishing that is required for the part.

Once the back of the cast part has been appropriately finished it can be removed from the roller conveyor and moved to a racking and/or curing area. If plant space and part size allow, a roller conveyor layout could be designed such that the parts remain on the conveyor while curing/demolding and the mold is continually pushed around the conveyor to minimize labor and handling.

Fast Stone® cement blends can be supplied to the continuous mixer in bags that are broken into the hopper, super sacks mounted directly over the hopper or via a ground feed hopper that is fed by super sacks and whose output is synchronised to the output of the continuous mixer. The standard hopper of the continuous mixer will hold approximately 300 lb of the Fast Stone LT® formula.

The continuous mixer is supplied with a variable-speed controller to control the rpm of the motor which in turn controls the slurry output within an approximately 25% range. Output is further controlled by the choice of three different-sized metering screws for the dry blend feeding powder into the wet mixing tube. The liquid components of water, Forton VF-774, plasticizer and pigments are charged into a 55 gallon drum equipped with an air-operated agitator to keep the blend properly dispersed. This blend is pumped to the mixing tube and the amount introduced into the mix stream is controlled by a flow meter mounted for easy viewing by the operator. The operator controls the workability of the mix by a simple controller using the visual observation of the mix discharging from the continuous mixer and correlated to the reading on the flow meter for easy reference once the parameters are decided. Different coloured batches can be mixed in different 55 gallon drums and easily switched by simpl changing the liquid feed tube. This side of the system is easily flushed with water for a complete cleaning.

Clean-up

The most important point of the entire process is that clean-up is truly less than 5 min. There are only two parts on the continuous mixer that need to be cleaned – the mixing shaft and the mix tube. These are easily handled by one man. The dry blend in the hopper is stable and requires no attention. When the operator is ready to run again he simply repositions the mixing shaft and the mix tube and turns the machine on.

Products

The ideal products that lend themselves to the production efficiencies of the continuous mixer and a Fast Stone® cement formula are high-volume, standard parts. They can be custom architectural parts of different colours and shapes, but they are parts that need to be made over and over again on a daily basis.

Examples are:

- balusters
- table tops
- fireplace surrounds and hearths
- countertops and vanities
- architectural moldings and column covers
- permanent formwork, and other products that have medium to high volume and need a fast turnover of moulds.

Pictures of simple plant set up making balusters

Permanent Formwork Panels

Vanity Top

Fireplace Surround

Summary and conclusions

With this system of material formulas and processing equipment we now have a water-based material of the most basic inorganic materials coupled with short demolding times. This system can now rival systems based on polyester and epoxy resins in terms of production output, but not be hindered by environmental or hazardous materials issues.

Bibliography

1. Harmon T., Molloy H., and Jones J. (1994) "Glass Fiber Reinforced Concrete with Improved Ductility and Long Term Properties", Thin Reinforced Concrete Products and Systems, ACI SP 146, pp. 79-90.
2. Gartshore, G.C., Kempster, E and Tallentire, A. G., (1991) "A New High Durability Cement for GRC products", 8th Biennale Congress of the GRCA , Maastricht, Netherlands pp. 3-12.
3. Garstshore, G. C., (1991) "A Recent Design Development for GFRC Composites", The Review, Design and Architecture, UK
4. Bijen, J., (1986) "Curing of GRC", 6th Biennial Congress of the GRCA, Edinburgh, Scotland pp. 71-78.