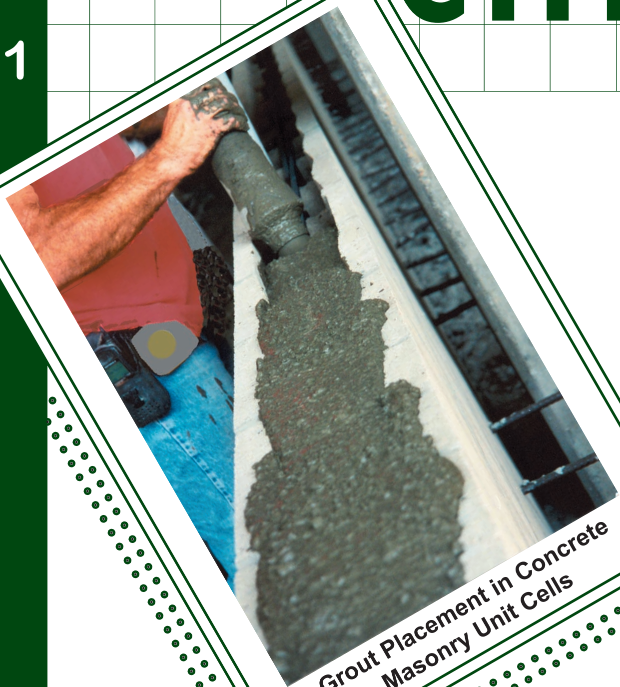
Engineering Notes For Design With Concrete Block Masonry

MASONRY CHRONICLES

Winter 2010-11



Grout Placement in Concrete Masonry Unit Cells

High Supplemental Cementitious Material (SCM) Grout Phase 2 and 3 Research

Abstract

Reducing the amount of Portland cement used in construction has important environmental benefits in terms of both the energy used to manufacture the cement as well as in lower CO_2 emissions. To improve the sustainability of concrete masonry construction, research was conducted to determine the viability of replacing up to 80% of the Portland cement in masonry grout with recycled materials. Various combinations of Class F fly ash and ground granulated blast furnace slag (GGBFS) were used to replace up to 80% by weight of the Portland cement in masonry grout. The resulting grouts were compression tested in accordance with ASTM C1019 at time intervals from 7 to 180 days. It was determined that high SCM grouts are a viable alternative for concrete masonry construction, with significant sustainable and economic benefits. For these high SCM grouts, it is recommended that the grout compressive strength be tested and evaluated at 42 days rather than 28 days.

Introduction

Concrete masonry has many sustainable benefits. Among them are its:

- long life cycle,
- durability/low maintenance requirements,
- structural capacity (ability to withstand earthquake and high wind events),
- sound-proofing,
- fire-proofing,
- insect-proofing,
- ability to provide a finished architectural surface (which eliminates the need for paints or other coatings),
- ability to incorporate recycled materials, and
- recyclability at the end of a building's life.

In addition to these benefits, the industry continues to investigate potential improvements. One such area is reducing the use of Portland cement in concrete masonry construction. Portland cement is an integral part of all concrete products, including concrete masonry units, mortar and grout. Portland cement acts as a structural binding agent: through the hydration process, the cement and water harden and bind the aggregates into a cohesive structural unit.

Portland cement production, however, generates almost one ton of carbon dioxide for every ton of cement produced. Replacing Portland cement with other cementitious products that do not entail CO_2 production presents an environmental advantage, if they can be incorporated without reducing the quality of the end product.

Concrete Masonry Association of California and Nevada

In concrete masonry construction, Portland cement is present in the units, mortar and grout. Reducing the amount of Portland cement in grout can be especially significant in high seismic regions. Because of the stringent structural requirements due to high seismic risk, concrete masonry walls are typically fully grouted, resulting in about half of the wall's volume being grout. It is estimated that over 1.3 million tons of Portland cement are used annually in the production of grout for concrete masonry walls in California and Nevada. Replacing a substantial percentage of Portland cement with recycled materials such as fly ash and ground granulated blast furnace slag (GGBFS) represents a significant potential to reduce CO_2 emissions associated with concrete masonry construction.

Research has been conducted to investigate the impacts of both moderate and high percentages of cement replacement on the compressive strength of masonry grout. The research was performed in three separate phases. This issue of *Masonry Chronicles* reports on Phases 2 and 3, completed in November, 2010. Phase 1 research results are reported on in the Summer/Fall 2009 issue of *Masonry Chronicles*. Phase 1 evaluated the compressive strength of grouts with 20%, 30%, 40%, 50% and 60% (by volume) replacement of Portland cement with Class F fly ash, and found that up to 20% fly ash replacement can be treated as conventional masonry grout. When 30% to 50% of Portland cement is replaced with Class F fly ash by volume, the compressive strength should be tested and evaluated at 42 days rather than 28 days.

Phase 2 research evaluated the compressive strength of grouts with 20%, 30%, 40%, 50% and 60% (by weight) replacement of Portland cement with Class F fly ash, as well as a control grout with Portland cement as the only cementitious material in the mix. Phase 3 research included grout mixes with both fly ash and GGBFS used to replace up to 80% of the Portland cement in masonry grout. The compressive strength of the supplementary cementitious materials (SCM) grouts was measured at time intervals of 7 to 180 days. Requirements for successful substitution are: high SCM grout meets all code requirements; and overall time to construct is not adversely affected.

Both fly ash and GGBFS are considered to be 100% recycled materials, and are recognized as such by green building programs such as by the U.S. Green Building Council's LEED™ rating program. The EPA also recognizes fly ash and GGBFS by favoring their procurement for federally funded projects. Both fly ash and GGBFS are less expensive that Portland cement, so their use produces a more economical, as well as sustainable, grout.

Fly Ash

Fly ash is a fine-grained particulate that results from burning coal. It is a pozzolan which combines with calcium hydroxide in the presence of water to form cementitious compounds. In 2006, 29.3 million metric tons of fly ash were used, almost half of which was used in concrete, concrete products and grout. However, the 29.3 million metric tons used was only about half of the fly ash produced, leaving a substantial potential for additional use.

Fly ash has been used as a cement replacement in Portland cement concrete for over 70 years. In concrete products, fly ash slows the rate of compressive strength gain and acts as a plasticizer, so it improves the workability of the plastic grout. Replacement of up to 15% (typically by weight) of Portland cement by Class F fly ash is currently a common practice in concrete and grout mix designs. Recent research has demonstrated that up to 50% of the Portland cement in masonry grout can be replaced by fly ash to produce a grout that meets all current code requirements for strength, and produces a more sustainable and economical system.

Ground Granulated Blast Furnace Slag

Blast furnace slag is a by-product of iron and steel production. Granulated blast-furnace slag is formed when molten blast furnace slag is quenched in water. It is non-metallic and highly cementitious in nature. Subsequent grinding reduces the particle size to the same fineness as cement, which is typically less than 3500 cm^2/g. The resulting ground granulated blast furnace slag (GGBFS) hydrates like Portland cement.

Substitutions of GGBFS for up to 50% of the Portland cement in concrete are common, and have been used for over 30 years. A 50% replacement of GGBFS for one ton of Portland cement reduces CO_2 emissions by one-half ton. In addition, grinding slag for cement replacement uses only about 25 percent of the energy needed to manufacture Portland cement.

GGBFS is governed by ASTM Specification C989. Three grades are specified by strength (determined by the slag quality and its fineness): Grade 120, Grade 100, and Grade 80. Grade 120 provides the greatest strength and is the most widely used.

Incorporating GGBFS into masonry grout may have several potential impacts. When compared to concrete mixes with no cement replacement, mixes incorporating GGBFS are generally observed to have improved workability and slower compressive strength development but equivalent or higher ultimate strength. GGBFS may also affect other concrete properties which are typically not of concern in masonry grout, such as permeability, flexural strength, color, salt scaling, and enhanced durability (sulfate resistance, chloride penetration and alkali-silica reactivity).

Scope of Research

Phase 2 of this investigation tested the compressive strength of a baseline grout mix (no Portland cement replacement) and five grout mixes with various amounts of fly ash replacing the Portland cement. Phase 3 tested the compressive strength of four grout mixes with various amounts of fly ash and ground granulated blast furnace slag replacing the Portland cement. All tests were conducted at Twining Laboratories in Long Beach, California.

The grout batches tested in Phase 2 and 3 are listed in Table 1. The percentages listed in Table 1 reflect the percentage of Portland cement replaced; not the percentage of GGBFS and/or fly ash in the mix. All reported percentages are by weight.

Sample Preparation

Ten grout batches were prepared; one for each mix outlined in Table 1. The quantities of each material were determined by weight. The materials were mixed in a mechanical mixer in accordance with ASTM C476, with sufficient water to provide a slump between 8 and 11 inches. Each mix was batched only one time, with all specimens from each batch cast as soon as possible following the conclusion of mixing.

Grout specimens were fabricated and tested per ASTM C1019 with one exception: grout was poured into the cores of 8 x 8 x 16 inch CMU to form the specimens (see Figure 1), rather than constructing a grout mold using four CMU. This exception was made in order to save laboratory space for such a large number of specimens, while still providing an absorptive mold for the grout specimen as required by ASTM C1019.

Table 1: Grout Batches Evaluated (Percentages by Weight)

	Total Percentage of Cement Replacement:	% Portland cement	% Fly ash	%GGBFGS
Mix 2-1	0	100	0	0
Mix 2-2	20	80	20	0
Mix 2-3	30	70	30	0
Mix 2-4	40	60	40	0
Mix 2-5	50	50	50	0
Mix 2-6	60	40	60	0
Mix 3-1	50	50	25	25
Mix 3-2	60	40	25	35
Mix 3-3	70	30	25	45
Mix 3-4	80	20	25	55

The 0% Portland cement replacement grout mix (i.e., a grout with Portland cement as the only cementitious material) was used as the basis for comparison.

For each grout mix listed in Table 1, three specimens were tested at each of the following specimen ages: 7, 14, 28, 42, 56 and 180 days. A total of 180 specimens were tested in both Phases.

Materials

The materials used in Phases 2 and 3 of the research were:

- Portland cement Type II complying with ASTM C150
- Coal fly ash Class F complying with ASTM C618
- GGBFS Grade 100 complying with ASTM C989
- Hollow concrete masonry units (CMUs) complying with ASTM C90
- Coarse aggregate (3/8-in. aggregate) complying with ASTM C404
- Washed concrete sand complying with ASTM C404
- Water

The grouted concrete masonry units were wet-cured in a moist room complying with ASTM C511. One day prior to testing, compression specimens meeting the dimensional requirements of ASTM C1019 (nominal 4 x 4 x 8 inch) were saw-cut from the CMU cores using a wet diamond saw (see Figure 2) and then returned to the curing environment until testing. The saw-cut specimens were capped with high-strength sulfur capping compound and tested in compression in accordance with ASTM C1019 (see Figure 3).

Figure 1: Grout Placement in Concrete Masonry Unit Cells

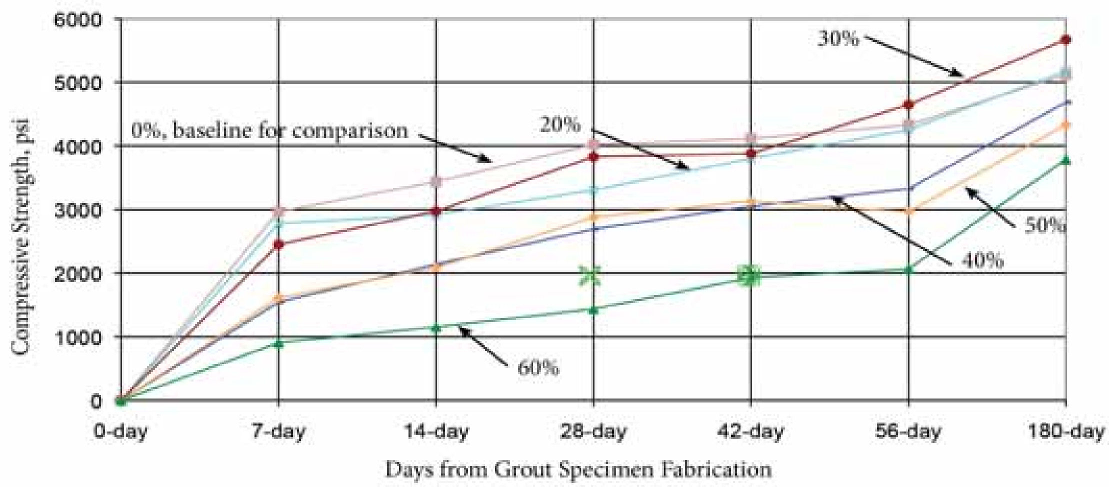
Figure 2: Test Specimens Being Saw-Cut From Concrete Masonry Unit Cells

Figure 3: Compression Testing of Grout Specimen

Test Results and Discussion

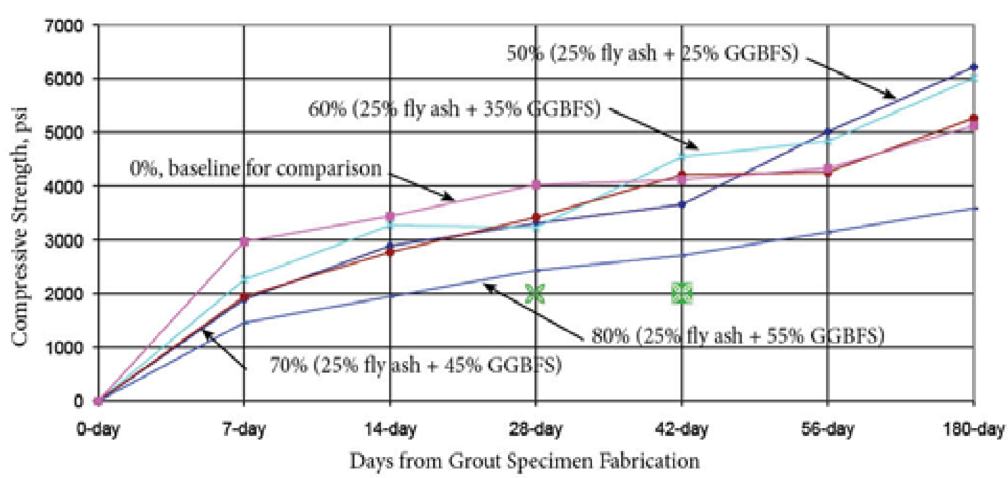
For each of the ten grout mixes, three specimens were compression tested at each time interval (7, 14, 28, 42, 56, and 180 days). The resulting compressive strengths for each group of three specimens were averaged together. These average grout compressive strengths are shown in Figures 4 and 5 for Phase 2 and Phase 3 research, respectively. Although testing of the 100% Portland cement (baseline for comparison) was conducted during Phase 2 of this research, the results are included in Figure 3 for comparison with the various levels of Fly ash/GGBFS cement replacement.

Figure 4: Measured Strength of Grouts with Moderate to High SCM Replacement of Portland Cement (Fly Ash Only)



Notes:
Percentages reflect the percentage of Portland cement, by weight, that was replaced with fly ash. All samples were wet-cured.
= Compressive strength criteria for conventional grout: 2,000 psi at 28 days
= Recommended criteria for high SCM grout: 2,000 psi at 42 days

Figure 5: Measured Strength of Grouts with High SCM Replacement of Portland Cement (Fly Ash & GGBFS)



Notes:
Percentages reflect the percentage of Portland cement, by weight, that was replaced with a combination of fly ash and ground granulated blast furnace slag (GGBFS). All samples were wet-cured.
= Compressive strength criteria for conventional grout: 2,000 psi at 28 days
= Recommended criteria for high SCM grout: 2,000 psi at 42 days

To determine viability, tested grout compressive strengths are compared to the minimum requirements of the *International Building Code* and ASTM C476, which require the grout to have a compressive strength of at least 2,000 psi at 28 days (shown on Figures 4 and 5 with the symbol). Figures 4 and 5 show that all of the tested grout mixes except the 60% fly ash replacement meet this criteria, with 28-day strengths exceeding 2,000 psi.

The results show that grout strength continues to increase when wet-cured beyond 28 days for both conventional grout (0% cement replacement) and moderate- to high-SCM grouts.

Phase 2 testing (Figure 4) shows that grout mixes with 20% and 30% fly ash cement replacement had strengths close to that of conventional grout throughout the time period evaluated. The 40% and 50% fly ash replacement grouts had lower strengths than the conventional, but still met the code-required minimum strength at both 28 and 42 days. The 60% fly ash replacement grout strength tested well below the conventional grout, throughout the time of test.

Phase 3 testing (Figure 5) shows that by 56 days of curing, all except the 80% cement replacement grout met or exceeded the strength of the conventional 0% grout. The 50%, 60% and 70% fly ash and GGBFS cement replacement grouts generally follow the strength development of the conventional 0% grout, and had tested compressive strengths within 20% of the conventional grout at 28 days and beyond. The 80% replacement grout meets the code-required strength of 2,000 psi at 28 days, although the measured strengths are consistently lower than the other tested grouts.

A numerical comparison of the tested grout strengths at 28 and 42 days is shown below in Table 2.

Conclusions

Phases 2 and 3 of this research found that:

- Grouts with up to 30% (by weight) of Portland cement replaced with Class F fly ash can be treated as conventional masonry grout.
- When 40% to 50% (by weight) of Portland cement is replaced with Class F fly ash, the compressive strength should be tested and evaluated at 42 days rather than 28 days.
- 60% (by weight) replacement of Portland cement with Class F fly ash alone does not appear to be a viable grout alternative.
- When 50 to 80% (by weight) of Portland cement is replaced with a combination of Class F fly ash and GGBFS (25% fly ash plus varying percentages of GGBFS), the grout compressive strength should be tested and evaluated at 42 days rather than 28 days.

High SCM grouts are a viable structural, sustainable and economic alternative for concrete masonry construction. The compressive strength testing at 42 days (versus the typical 28 days) should not have a significant effect on the overall building project schedule. Prism testing in addition to grout specimen testing may be warranted when using high SCM grouts in masonry construction.

Table 2: Comparison of 28-Day and 42-Day Grout Compressive Strengths for Research Phases 2 and 3

Grout Mix	Grout (% cement replacement):	28-day strength, psi	% above 2,000 psi	42-day strength, psi	% above 2,000 psi
Mix 2-1	0%	4,023	101	4,117	106
Mix 2-2	20%	3,307	65	3,803	90
Mix 2-3	30%	3,830	92	3,880	94
Mix 2-4	40%	2,693	35	3,053	53
Mix 2-5	50%	2,880	44	3,130	57
Mix 2-6	60%	1,437	-28	1,930	-3
Mix 3-1	50%	3,307	65	3,655	83
Mix 3-2	60%	3,227	61	4,543	127
Mix 3-3	70%	3,417	71	4,207	110
Mix 3-4	80%	2,430	22	2,707	35

Acknowledgements
The following organizations have supported this study, and without their monetary contributions, this test program would not have been possible:
1. Arizona Masonry Guild
2. Concrete Masonry Association of California and Nevada
3. Illinois Masonry Institute Promotion Trust
4. Masonry Institute of America
5. Northwest Concrete Masonry Association
6. Utah Masonry Council

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    - C476, *Standard Specification for Grout for Masonry*, 2010.
    - C511, *Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes*, 2009.
    - C618, *Standard Specification Coal Fly Ash and raw or Calcined Natural Pozzolan for Use in Concrete*, 2008.
    - C989, *Standard Specification for Slag Cement for Use in Concrete and Mortars*, 2009.
    - C1019, *Standard Test Method for Sampling and Testing Grout*, 2009.

This edition of Masonry Chronicles was written by *Maribeth S. Bradfield, P.E., LEED® AP, Bradfield Consulting.*

About the Author

Maribeth Bradfield is a consulting engineer who specializes in energy efficiency. Recent work includes projects in energy code compliance, building energy modeling and technical publications and articles. She previously worked for the National Concrete Masonry Association, where she was involved in energy standard development, coordinating energy efficiency programs for the Association, and developing technical publications. Ms. Bradfield is a member of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the American Concrete Institute and The Masonry Society.

Ms. Bradfield earned her Bachelor of Science Degree in Mechanical Engineering from Virginia Tech. She is a registered Professional Engineer in the State of Virginia and a LEED AP.

Concrete Masonry Association
of California and Nevada
6060 Sunrise Vista Drive, Suite 1990
Citrus Heights, CA 95610
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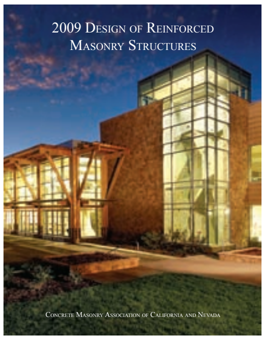

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