Engineering Notes For Design With Concrete Block Masonry

MASONRY CHRONICLES

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Grout Specimen During Compression Test

Going Green with Concrete Masonry Grout

Abstract

Concrete, which is a product containing Portland cement, is the second most used building material (after water) worldwide. Masonry grout is similar to concrete except that grout has a high water content and smaller size aggregates. The excess water is immediately absorbed into the masonry units during placement, which lowers the water/cement ratio and allows for a normal hydration process. During the process of making Portland cement, more than 1/5 ton of carbon dioxide is produced for every ton of cement with 60% of the carbon dioxide production due to a chemical reaction. There is currently no viable remedy to reduce the carbon dioxide emission due to this chemical process. To limit carbon dioxide emission from Portland cement production, cement use in concrete products can be reduced (e.g. concrete and grout) [1]. However, the reduction in Portland cement content must not compromise strength or building processes (time).

When hollow concrete masonry is used for construction in high seismic regions, structural designs typically require fully grouted walls. For a fully grouted 8″x8″x16″ concrete masonry unit (CMU), 52% of total volume is grout. Since half of the volume of a fully grouted 8″x8″x16″ CMU wall would consist of grout, it then makes sense to investigate the grout mix as a potential source for sustainable improvements.

This issue of “Masonry Chronicles” reports on testing of grout mixes substituting various proportions of fly ash for Portland cement, and tested in compression to ASTM standards [2]. The grout mixes consisted of fly ash percent replacement (by volume) of 0, 20, 30, 40, 50, and 60%. A 100% Portland cement (no fly ash replacement) grout mix established the base line for the test. The grout mix samples were cured within the cells of 8″x8″x16″ CMUs. The curing process consisted of one set of samples cured wet and a second set cured dry. The samples were tested at 7, 14, 28, 42, and 56 days.

Testing verified that replacing 20% to 50% of the volume of Portland cement in grout with Class F fly ash met the minimum code strength requirement of 2,000 psi within the standard construction time duration of 28 days [3].

Testing also indicated that using Portland cement replacement of 60% has a detrimental strength effect, even after 56 days.

Since grout is a component of masonry construction, masonry prism tests should be conducted when using Portland cement replacement volumes up to 50%.

Concrete Masonry Association of California and Nevada

Introduction

Cement is the foundation of infrastructure as it is used in construction of freeways, canals, dams, power transmission towers, building foundations, high-rise buildings, free-standing walls, soil retaining walls, and other prominent structures. In masonry construction, Portland cement is used in the manufacture of hollow concrete masonry units (CMUs) conforming to ASTM C90, in mortar conforming to ASTM C270 and in grout conforming to ASTM C476.

A comparison analysis was conducted between a 6-inch solid tilt-up concrete wall using 15% fly ash replacement of Portland cement, and a fully grouted 8-inch thick CMU wall using 50% fly ash replacement of Portland cement in the grout [4]. The analytical results show that the CMU walls require 2.6 fewer pounds of Portland cement for every square foot of wall even when the concrete tilt-up wall is two inches less in thickness.

Why is Using Less Cement Good?

The cement manufacturing process transforms raw materials into a binding material. The basic cement raw material is limestone mined from a quarry. The limestone is then mixed with clay in a crusher, sand is added and the mixture is ground into a fine powder. The powder is heated as it passes through a Pre-Heater Tower into a large kiln. The powder is heated to over 2700^{o}F to produce clinker. The clinker is combined with small amounts of gypsum and limestone, and then finely ground so that it passes through a sieve fine enough to hold water [5]. This entire Portland cement manufacturing process is energy intensive.

60% of the carbon dioxide emissions caused by making Portland cement are from chemical reaction processes, while the balance is from fuels used in production (for the kiln and in power generation) [6]. Although technology may mitigate emissions from fuels, to date, there is no viable mitigation for emissions from the chemical process. There is however ongoing research in this area [7].

The cement industry contributes about 5% to the global anthropogenic carbon dioxide emissions [8]. California is the largest Portland cement producing state in the United States, accounting for 10% to 15% of the U.S. Portland cement production [9]. China alone manufactures and uses 45% of the Portland cement produced worldwide [6].

Since Portland cement will usually be produced close to high construction density regions, more cement will be produced in the developing parts of the world. This, in turn, will produce more carbon dioxide in those regions. In 2006, California legislated an effort to implement a reduction of carbon dioxide emissions to the 1990 levels by the year 2020 [10]. In the Portland cement manufacturing process, less Portland cement production translates to less production of carbon dioxide. The pragmatic goal is to produce concrete and grout using less Portland cement to avoid a negative environmental and economic impact.

Experimental Study

When hollow concrete masonry is used for construction in high seismic regions, structural designs typically require close spacing of reinforcement and fully grouted walls. In a fully grouted 8"x8"x16" CMU wall, 52% of total volume is grout.

As a sustainable improvement for masonry grout, an experimental investigation into the partial replacement of Portland cement by fly ash in masonry grout was initiated [11]. All tests were conducted at Twining Laboratories, Long Beach, California.

Scope

The scope of the investigation was to test (in compression) various grout mixes that had partial fly ash replacement for Portland cement. A set of sample tests consisted of the following percentages of fly ash replacement (by volume) 0, 20, 30, 40, 50, and 60%. A 0% Portland cement replacement grout mix was the base line test. Grout samples were cured within the cells of 8"x8"x16" CMUs. The curing process consisted of one set of samples cured wet and a second set cured dry. The samples were tested at 7, 14, 28, 42, and 56 days.

Materials

- Portland cement Type II complying with ASTM C150.
- Coal fly ash Class F complying with ASTM C618.
- Hollow concrete masonry units (CMUs) complying with ASTM C90.
- Sand
- Pea gravel (3/8" aggregate)
- Water

Table 1 shows the physical properties of the materials used.

Table 1: Physical Properties of Materials

Material	Loose Unit Weight (lb/ft^3)	Specific Gravity (SSD)
Portland Cement	94.0	3.15
Fly Ash	72.0	2.23
Sand	71.664 - 75.850	2.59
Pea Gravel	80.713 - 82.541	2.59

Sample preparation

The number of grout specimens required in this investigation for each curing process is shown in Table 2.

Table 2: Number of Grout Test Specimens for Each Curing Process

Cementitious Material		Test Age (Days)				
		7	14	28	42	56
Cement (%)	Fly Ash (%)	Number of Specimens				
100	0	3	3	3	3	3
80	20	3	3	3	3	3
70	30	3	3	3	3	3
60	40	3	3	3	3	3
50	50	3	3	3	3	3
40	60	3	3	3	3	3
Total Number of Specimens = 90						

One set of grout samples was cured wet, while the other was cured dry for a total of 180 specimens required for the entire testing protocol.

The materials for the coarse grout were proportioned by volume and batching was performed in accordance with Table 1 of ASTM C476. The materials were mixed in a mechanical mixer in accordance with ASTM C476 as shown in Figure 1.

Figure 1: Adding Grout Materials to a Mechanical Mixer

Grout specimens were prepared and tested in accordance with ASTM C1019. In order to save material, space and simulate water absorption required in ASTM C1019, the specimens were cast within the hollow cells of 8”x8”x16” CMUs as shown in Figure 2.

Figure 2: Grout Placement in Concrete Masonry Unit Cells

Half of the grout specimens were cured in a dry room, complying with ASTM C157. The other half were cured in a wet room complying with ASTM C511 as shown in Figure 3

(A) **(B)**

Figure 3: Grout Specimen Curing in (A) Dry Conditions and (B) Wet Conditions

Compression test samples were made from the grout specimens by saw cutting the grout specimen to the dimensional requirements of ASTM C1019 (as shown in Figure 4). The test samples were cut two days prior to testing. After cutting, samples were returned to their specific curing environment until testing. The specimens were capped and tested in compression in accordance with ASTM C1019 as shown in Figure 5.

Figure 4: Saw-Cutting of Grout Specimens from Concrete Masonry Unit

(A) **(B)**

Figure 5: Grout Specimens (A) During Compression Test and (B) After Testing

Compression Test Results and Discussion

Grout specimens were cured in either dry or wet conditions. The average compression strength (of three specimens) for the dry cured grout specimens made by replacing 0, 20, 30, 40, 50 and 60% of Portland cement with Class F fly ash, and tested at 0, 7, 14, 28, 42 and 56 days after casting, are shown in Figure 6. Corresponding compressive strengths for wet cured grout specimens are shown in Figure 7.

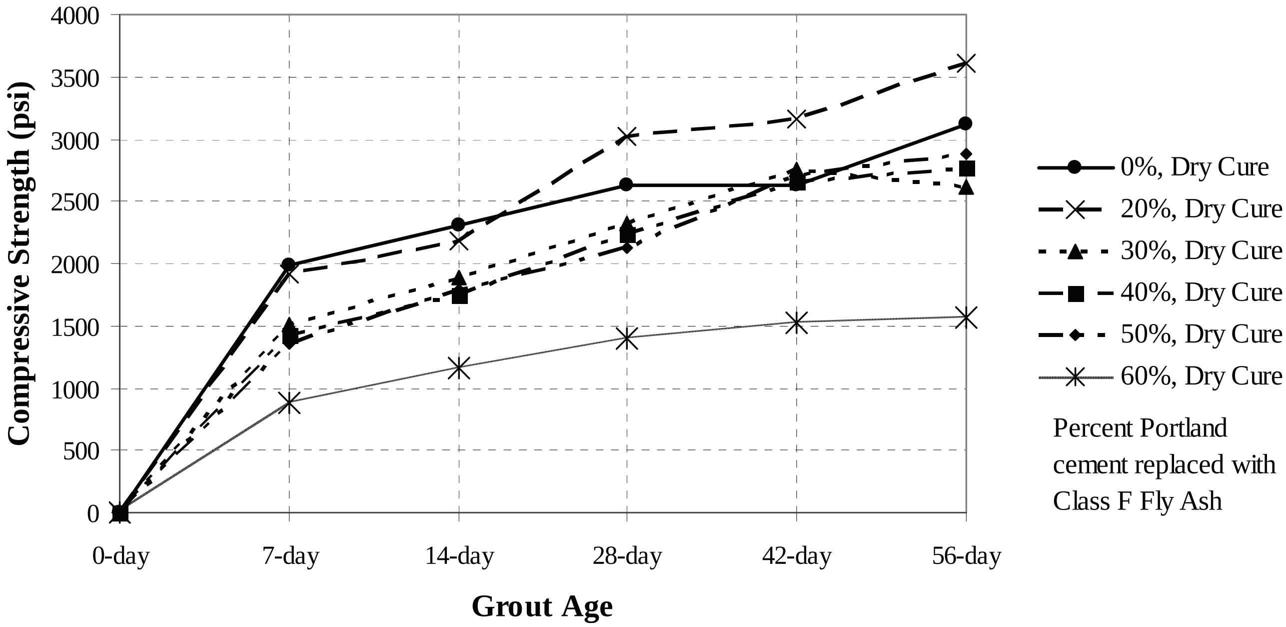

Figure 6: Compressive Strength of Dry Cured Grout Specimens

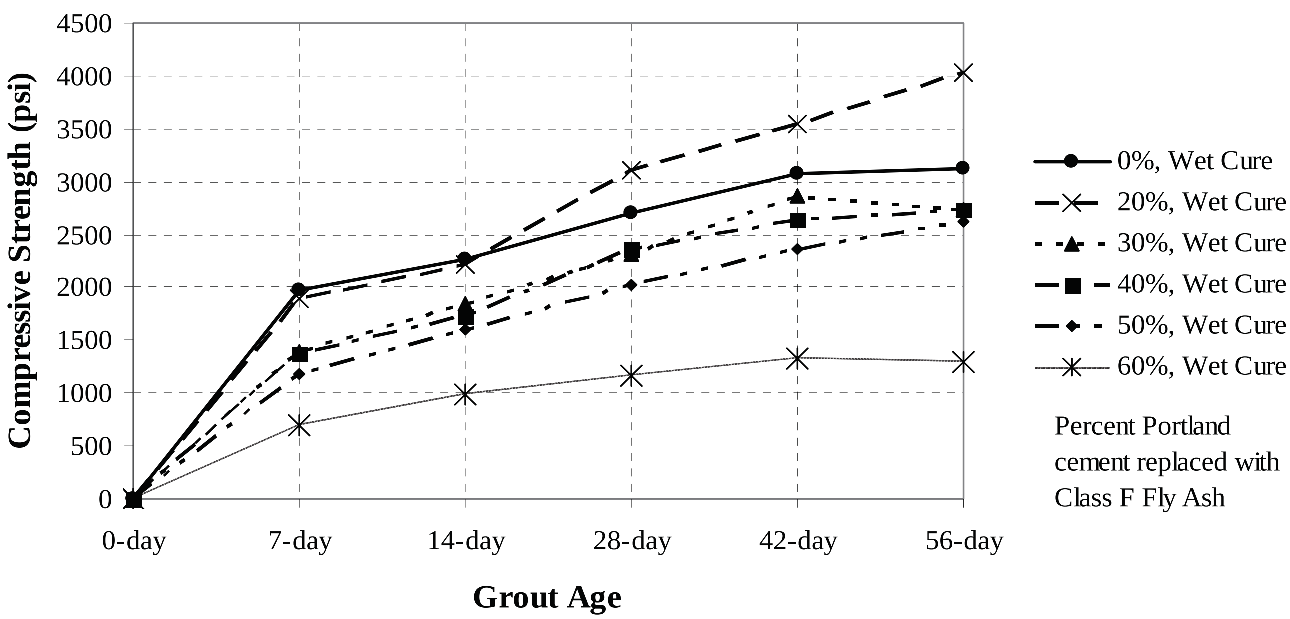

Figure 7: Compressive Strength of Wet Cured Grout Specimens

Evaluation of the grout test results is based on the building code [12] requirement or a minimum compressive grout strength of 2000 psi at 28 days. Using this baseline, it is clear from Figures 6 and 7 that regardless of the curing environment, all grout mixes replacing up to 50% of Portland cement with Class F fly ash meet or exceed the minimum code requirements for 28-day compressive strength.

Tests were conducted using 60% Portland cement replacement with Class F fly ash. Grout mixes were batched by volume and the minimum compressive strength of 2,000 psi required by code was not reached at 56 days in either curing environment.

Replacing 20% of Portland cement with Class F fly ash resulted in grout strengths exceeding strengths in mixes without fly ash replacement when comparing the two mixes at 14 days and beyond. The 28-day grout strengths were at least 1.5 times the minimum code compressive strength requirements regardless of the curing environment.

Dry cured grout mixes with 30 through 50% replacement of Portland cement had 42-day compressive strengths of approximately of 2,600 psi. Dry-cured grout samples averaged 1.25 times the minimum code compressive strength requirement. The average increase in strength between the 42-day and the 56-day compressive strengths was 135 psi.

The 42-day compressive strength of wet cured grout mixes with Portland cement replacement of 30 through 50% followed the same trend as those of dry cured mixes, except that the compressive strength was approximately 2,500 psi. Wet-cured grout samples averaged 1.25 times the minimum code compressive strength requirement. Again, no significant increase in strength was observed between the 42-day and the 56-day strengths as the compressive strength of both was approximately 2,750 psi.

Conclusion

The use of fly ash in concrete products slows the rate of compressive strength gain. This trend was no different with masonry grout as can be observed in Figures 6 and 7. Replacement of up to 15% of Portland cement by Class F fly ash (typically by weight) is currently a common practice in concrete and grout mix designs. From the results of this investigation, the following conclusions may be reached.

- 20% Portland cement replacement in grout (by volume) with Class F fly ash in this test program had no effect on the initial rate of compressive strength gain. After 14 days, the grout mix with 20% Portland cement replacement produced higher strengths than the grout with no fly ash regardless of the curing environment.
- For dry cured samples (dry curing is the practical curing method in the field), there was no significant difference in compressive strength of the grout when 30 to 50% of the Portland cement was replaced with Class F fly ash by volume.
- 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. This should not affect the project construction schedule.
- Portland cement should not be replaced with Class F fly ash by more than 50% by volume.

Additional tests are currently being conducted with grout mix designs based on weight (more common method of batching than volume in practice). All samples will be wet cured and the testing period will extend to 180 days instead of the 56 days used in this comparison test. Portland cement replacement percentages with fly ash will be similar to those used in this comparison test.

Tests in this comparison study were only for the grout component of masonry. Masonry consists of multiple components – block, mortar, grout, and reinforcement. These tests indicate that up to a 50% replacement of cement in grout MAY BE a sustainable alternative for masonry. In addition, high volume replacement of Portland cement with fly ash in concrete products acts as a plasticizer, which in grout mixes may help increase the flowability of grout in concrete masonry wall construction. Testing of both grout samples and composite prisms may be considered when using grout mixes with high replacement of Portland cement with class F fly ash.

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5. Northwest Concrete Masonry Association
6. Utah Masonry Council

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  C150 *Standard Specification for Portland Cement,* Vol. 04.01
  C157 *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete,* Vol. 04.02
  C270 *Standard Specification for Mortar for Unit Masonry,* Vol. 04.05
  C476 *Standard Specification for Grout for Masonry,* Vol. 04.05
  C511 *Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes,* Vol. 04.01
  C618 *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete,* Vol. 04.02
  C1019 *Standard Test Method for Sampling and Testing Grout,* Vol. 04.05

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