REPLACEMENT OF PORTLAND CEMENT WITH SUPPLEMENTAL CEMENTITIOUS MATERIALS IN MASONRY GROUT

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A comprehensive testing program was developed to determine the viability of replacing high amounts of Portland cement in masonry grout with other cementitious materials. Various combinations of class F fly ash and ground granulated blast furnace slag were used to replace Portland cement. The objective was to determine if required minimum grout strengths could be maintained with high levels of these supplemental cementitious materials.

In Phase I specimens were dry and wet cured while in Phases II, III, IV, V they were wet cured. In Phase I mixes were proportioned by volume while in the other Phases they were proportioned by weight. Mixes in Phases I and II were batched with 0%, 20%, 30%, 40%, 50% and 60% fly ash. Mixes in Phase III were batched with 50%, 60%, 70% and 80% fly ash-ground granulated blast furnace slag. In phase IV mixes were batched with 45%, 55%, and 65% fly ash. In phase V mixes were batched with 65%, 75%, and 85% fly ash-ground granulated blast furnace slag. Fly ash in mixes III and V was limited to 25%.

Based on the tests results grouts with up to 40% class F fly ash and 80% class F fly ash-ground granulated blast furnace slag can essentially be treated as conventional masonry grout.

Keywords: *Grout, Cementitious Materials, Strength, Fly Ash, Slag, Portland Cement*

INTRODUCTION

Concrete masonry has many proven sustainable benefits including low maintenance requirements, long life cycle, high recyclability, high reusability potential, and lower energy cost over life span. The concrete masonry industry could become even more sustainable by reducing the use of Portland cement, whose production generates approximately one ton of carbon dioxide per produced ton (Hanle et al 2006). A possible way to achieve such a vision is to increase the substitution levels of fly ash and ground granulated blast furnace slag for Portland cement in masonry grout—low substitution levels have already been used for many years. The high volume replacement of Portland cement will most likely not cause a decrease in cement's production but it will cause a better use of available resources.

There are several benefits of increasing the substitution levels of fly ash and slag for Portland cement in masonry grout. The benefits include (a) using 100% recycled materials, (b) making construction more affordable because less expensive materials are used, (c) reducing their disposal in landfills, ponds, and (in many places around the world) in river systems (d) making possible construction industry expansion without increasing green-house gases emission, (e) making the masonry concrete construction more competitive, and (f) alleviating the demand for Portland cement especially in developing countries where masonry construction is the preferred construction method. All these benefits, however, can only be achieved if these materials can be used without compromising building code requirements.

A comprehensive research program has been designed and is currently under way to determine if required minimum masonry strengths, obtained from testing masonry prisms, can be maintained with high levels of fly ash and slag grouts. In case the minimum strength is not obtained at the specified 28-day age, the research will determine at what age strength tests of masonry prisms can be then performed. The research is in its infancy and its impact can be significant and broad, even transcending time by benefiting generations to come.

FLY ASH AND SLAG

Fly ash is a fine-grained particulate produced during coal combustion. It is a pozzolan which combines with calcium hydroxide in the presence of water to form cementitious compounds. Fly ash for use in concrete products in the United States must meet the requirements of ASTM C618 (ASTM), which defines two classes of fly ash: Class F (which requires a source of calcium hydroxide such as cement or lime) and Class C (self-cementing). Class F is typically used in concrete products. 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 grout mix designs.

Blast furnace slag is a by-product of the iron and steel industry. Granulated blast-furnace slag is formed when molten blast furnace slag is quenched in water. Grinding reduces the particle size of the granulated blast-furnace slag to the same fineness as cement, and the resulting product, ground granulated blast furnace slag (GGBS), is highly cementitious and hydrates like Portland cement. Substitutions of GGBS for Portland cement in concrete are common and have been used for over 30 years. A 50% GGBS replacement, a common amount in the US concrete industry, reduces carbon dioxide emissions by approximately one-half ton (Hogan et al 2001). Furthermore, grinding slag for cement replacement uses about only 25% of the energy needed to manufacture Portland cement (Chesner et al 1998). In the US composition of GGBS is governed by ASTM Specification C989 (ASTM) and three grades are specified; Grade 120 provides the greatest strength and is the most widely used. Compared to concrete mixes with no cement replacement, mixes incorporating GGBS have improved workability and slower compressive strength development but equivalent and even higher ultimate strength.

HIGH VOLUME SUBSTITUTIONS

High volume substitution of Portland cement is a somewhat new development. In 1985, the concrete research group from the materials technology laboratory at the Canada Centre for Mineral and Energy Technology (CANMET-MTL) began developing a high volume fly ash concrete (HVFAC). That concrete utilizes proper mixture proportioning and careful selection of materials to minimize the amount of Portland cement while producing high-quality concrete. HVFAC has low Portland cement content, low water-to-cementitious materials ratio (w/cm) and incorporates up to 55% fly ash. Because of the low w/cm, however, superplasticizers may be needed to increase the fresh concrete workability. Over the years, CANMET-MTL, in partnership with the Electric Power Research Institute, U.S.A., Canadian Electrical Association, and other public and private partners, has published a large amount of data on the properties of HVFAC (Malhotra 2002, Bouzoubaa and Malhotra 2001). HVFAC has been gradually gaining acceptance (Manmohan and Mehta 2002, Cross et al 2005) among engineers.

EXPERIMENTAL PROGRAM - OVERVIEW

A comprehensive research program was designed and is being conducted at Brigham Young University under the direction of Dr. Fernando Fonseca in collaboration with Mr. Kurt Siggard, Executive Director of Concrete Masonry Association of California and Nevada. The first stage of the research program was to test grout specimens constructed with high volumes of fly ash and fly ash-slag. The second stage involved the testing of masonry prisms assembled with the same type of grouts. The results of the first state of the research are being reported in this article.

Chapter 3 of the United States Building Code Requirements for Masonry Structures (TMS 2008) specifies that the compressive strength of the grout, f'_g, must be equal or exceed the specified compressive strength of the masonry, f'_m, which in turn must be equal or exceed 10.3 MPa at 28 days. Chapter 2 of the code, however, does not specify minimum compressive strengths for grout and concrete masonry. According to the United States Specification for Masonry Structures (TMS 2008), however, concrete masonry must either comply with the unit strength method; have a grout compressive strength equal to or exceeding f'_m but not less than 13.8 MPa at 28 days; or meet ASTM C476 (ASTM) specifications, which requires grout to have a minimum compressive strength of 13.8 MPa at 28 days. All of the above means that grout must have a minimum compressive strength of 13.8 MPa or the f'_m whichever is greater.

The first stage of the research, reported herein, evaluated the compressive strength of several grout mixes with different replacement rates of Portland cement by comparing the obtained results to determine which mixes reached the compressive strength of 13.8 MPa at 28 days.

Grout mixes were proportioned by either volume or weight; the material was mixed in a mechanical mixer in accordance with ASTM C476 (ASTM). The ratio of water-cementitious material remained constant at approximately 0.7 but slump varied slightly from mix to mix. Slump testing was conducted according to ASTM C143 (ASTM) and ranged from 200 to 280 mm. Specimens were constructed and tested per ASTM C1019 (ASTM) with one exception: grout was placed into the cores of 200 x 200 x 200 mm CMU to form the specimens, rather than the four CMU mold. This method provided the absorptive mold for the grout specimen as required by ASTM C1019. Grout mixes were cured in dry and wet conditions. Specimens cured in a dry condition were placed in a dry room in accordance with ASTM C157 (ASTM). Grout samples cured in wet condition were placed in a fog room complying with ASTM C511 (ASTM). Compression specimens meeting the dimensional requirements of ASTM C1019 were saw-cut from the CMU cores using a wet diamond saw and then returned to the curing environment until testing. The saw-cut specimens were capped with capping compound and tested in compression in accordance with ASTM C1019.

EXPERIMENTAL PROGRAM – PHASE I

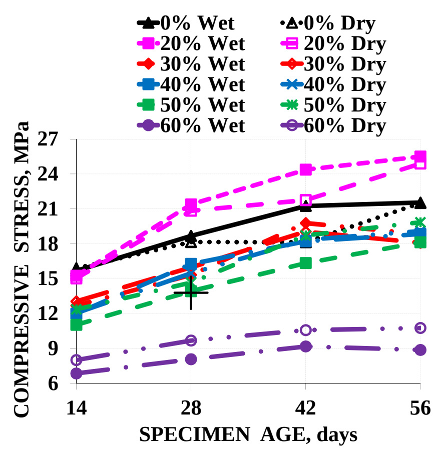
The pilot testing program was conducted by the Concrete Masonry Association of California and Nevada (Mwangi and Baltimore 2009, Siggard 2010) to determine the feasibility of using higher substitution levels of fly ash and slag for Portland cement. In this preliminary phase, mixes were proportioned by volume and specimens were dry and wet cured. Mixes were batched with 0%, 20%, 30%, 40%, 50% and 60% fly ash. The following materials were used: Portland cement Type II complying with ASTM C150 (ASTM); coal fly ash Class F complying with ASTM C618 (ASTM); hollow concrete masonry units complying with ASTM C90 (ASTM); sand; pea gravel (9.5 mm aggregate), and water. Specimens were tested in accordance with ASTM C1019 at 7, 14, 28, 42, and 56 days. Figure 1 shows the grout placement and curing conditions. Three specimens were tested for each replacement rate, age, and curing condition.

Figure 1: Grout Placement and Dry and Wet Curing of Specimens

Results of phase I tests are summarized in table 1. Results for the 7-day tests are not shown.

Table 1: Test Results (MPa)- Phase I

	14	28	42	56
0%W	15.7	18.7	21.2	21.5
0%D	15.9	18.1	18.1	21.5
20%W	15.2	21.4	24.4	25.5
20%D	15.0	20.8	21.7	24.9
30%W	12.7	15.3	19.8	18.8
30%D	13.0	16.0	19.0	18.1
40%W	12.0	16.3	18.2	18.8
40%D	12.0	15.5	18.3	19.1
50%W	11.0	13.9	16.3	18.1
50%D	12.4	14.7	18.7	19.8
60%W	6.8	8.1	9.2	8.9
60%D	8.0	9.7	10.6	10.7



For the 0%, 20%, 30%, and 40% replacement rate, the wet and dry curing methods generally yielded similar compressive strength results except for the 0% and the 20% rate at 42 days. In these two instances the strength of specimens cured in dry conditions were lower than those cured in wet conditions. For the 50% and 60% replacement rate, the dry curing method yielded slightly higher strength than the wet curing method regardless of specimen age.

Specimens of all replacement rates and curing conditions, except the 60% rate, reached the minimum 13.8 MPa compressive strength at the specified 28 days.

EXPERIMENTAL PROGRAM – PHASES II AND IV

Two changes were made during Phases II and IV of the testing program: mixes were proportioned by weight, a more common practice in the United States, and specimens were wet cured only, which is in accordance with ASTM C1019 (ASTM) and during the pilot testing yielded more conservative results. Mixes in Phase II were batched with 0%, 20%, 30%, 40%, 50% and 60% fly ash. Phase IV tested mixes with 45%, 55%, and 65% replacement rates to better define the results. The materials used were similar to those used in Phase I and complied with the prescribed ASTM standard. Specimens were tested in accordance with ASTM C1019; phase I specimens were tested at 7, 14, 28, 42, and 56 days; phase IV specimens were not tested at 7 days. Three specimens were tested for each replacement rate and age. Figure 2 shows the samples of Phase IV prior to and during casting. Figure 3 shows the saw-cutting of a grout sample from the concrete masonry unit (CMU) and the testing of a sample.

Figure 2: CMUs Prior to Casting Grout Samples and Grout Samples During Casting

Figure 3: Saw-Cutting of a Grout Specimen and Grout Sample During Testing

Tests results for Phases II and IV are shown in Figure 4.

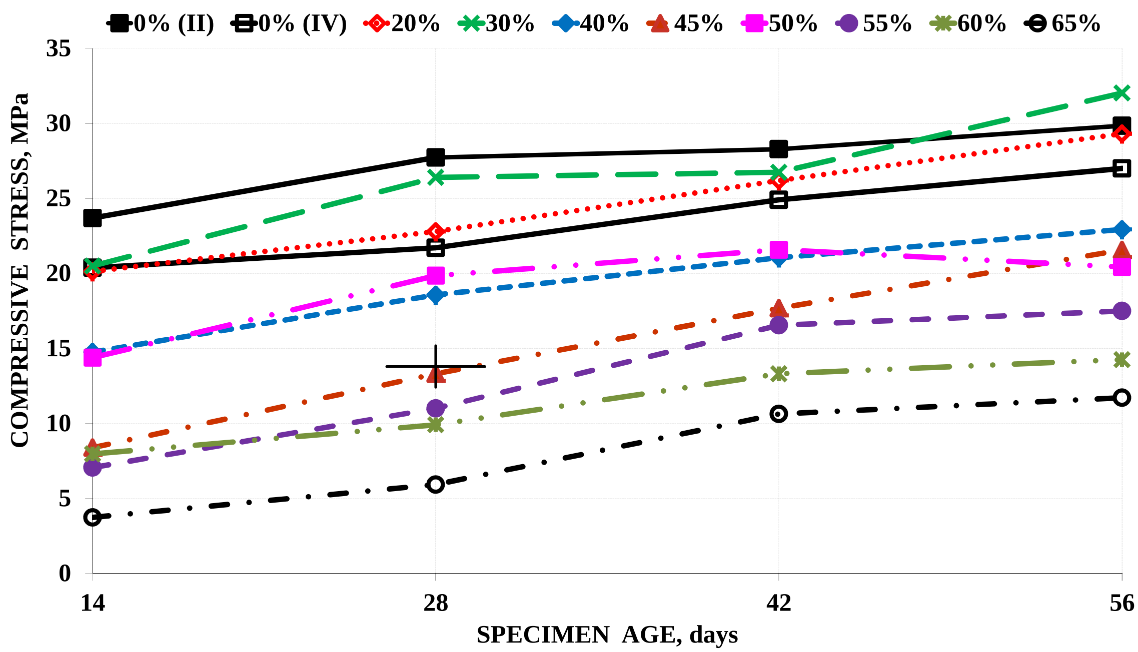


Figure 4: Grout Strength – Fly Ash Replacement Set

Results show some variability and even what appear to be some discrepancies: the capacity of phase IV specimens with 0% replacement is lower than that of phase II specimens; the capacity of specimens with 30% replacement is slightly higher than that of specimens with 20% replacement; the capacity of the specimens with 40% and 50% replacement is similar up to 42 days but then there is a decrease in strength for the 50% replacement set at 56 days, which is atypical since fly ash mixes typically gains strength with time; the capacity of specimens with 45% replacement appears to be low— it is much lower than that of specimens with 40% replacement and only slight higher than that of specimens with 55% replacement. These differences and somewhat discrepancies may be due to the difference in materials and/or testing equipment and personnel.

Despite the differences and even discrepancies, results clearly show that 40% fly ash substitution achieved the minimum required strength at 28 days and that 60% fly ash substitution achieved the minimum required strength at 56 days.

EXPERIMENTAL PROGRAM – PHASES III AND V

Phase III tested mixes with 50%, 60%, 70% and 80% fly ash-ground granulated blast furnace slag and phase V tested mixes with 65%, 75%, and 85% fly ash-ground granulated blast furnace slag. Fly ash content in these mixes was 25%. Phase V was used to confirm and refine the results obtained during Phase III. The materials used were similar to those used in Phase I and complied with the prescribed ASTM standards. Specimens were tested in accordance with ASTM C1019. Phase III specimens were tested at 7, 14, 28, 42, and 56 days but phase V specimens were not tested at 7 days. Mixes were proportioned by weight and specimens were wet cured. Tests results for the fly ash-GGBS replacement set are shown in Figure 5.

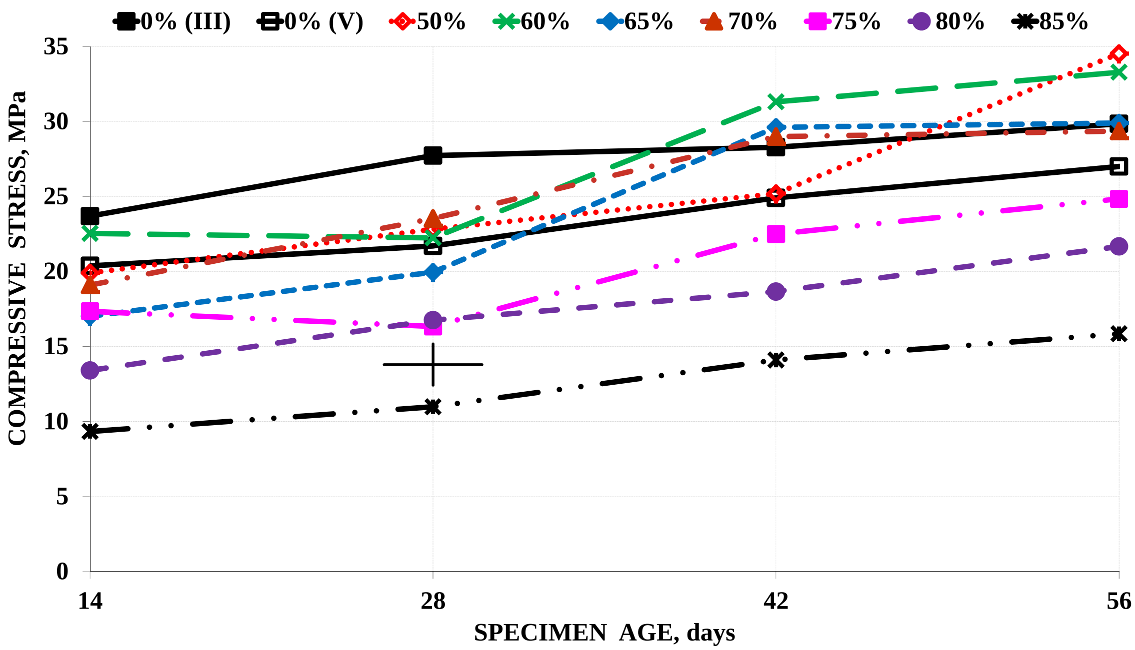


Figure 5: Grout Strength – Fly Ash-GGBS Replacement Set

Results for the fly ash-GGBS replacement set also show some variability. There is also what appears to be a discrepancy: the capacity of specimens with 50% replacement is lower than that of specimens with 60%, 65%, and 70 % replacement until 42 days but at 56 days the capacity of specimens with 50% replacement becomes higher than that of specimens with 60%, 65%, and 70 % replacement as it should be. These irregularities and discrepancies are also most likely due to difference in materials and/or testing equipment and personnel.

Results, nonetheless, clearly show that specimens with 80% fly ash-GGBS substitution achieved the minimum required strength at 28 days and specimens with 85% fly ash-GGBS substitution achieved the minimum required strength at 56 days.

CONCLUSIONS

High volume fly ash and fly ash-ground granulated blast furnace slag replacement of Portland cement is a viable alternative to make concrete masonry construction more economical and sustainable. The research presented herein clearly shows that specimens constructed with 40% fly ash and 80% fly ash-ground granulated blast furnace slag substitutions of Portland cement achieved the minimum compressive strength required at 28 days. Based on the tests results grouts with up to 40% class F fly ash and 80% class F fly ash-ground granulated blast furnace slag can essentially be treated as conventional masonry grout.

Results also show that specimens constructed with 60% fly ash and 85% fly ash-ground granulated furnace blast slag substitutions of Portland cement achieved the minimum compressive strength required at 56 days. In some cases, structures may not need to achieve the minimum strength at 28 days. For such cases, the results of this research provide another viable option to engineers to make concrete masonry construction more economical and sustainable.

Results appear to be somewhat sensitive to the regionally available materials used, testing equipment, and technician conducting the test; therefore, masonry grout mix designs incorporating high volumes of supplementary cementitious materials should be evaluated and tested using regionally available materials by masonry grout suppliers. More research to determine the correlation between these factors and the compressive strength of masonry prisms constructed with grout containing high volume of supplemental cementitious materials is necessary to achieve a confidence level to propose any changes to current United Stated codes and standards.

ACKNOWLEDGEMENTS

This testing program would not have been possible without their support of the following people and organizations: Paul Jahn from Ash Grove Packaging; David Anderson, Rodney Mayo, and David Wilson from BYU; Rick Child from Child Enterprises; Kevin Hatfield from Doyle Hatfield Masonry; Jim Johnson and Chris Bedford from Headwaters; Heath Holdaway from IMS Masonry; Rob Shogren and Todd Sherman from Lafarge; Dennis W. Graber, Nick Lang, Bob Thomas and Jason Thompson from National Concrete Masonry Association; Wade Ficklin, Paul Kamnikar and Gerald Travis from Oldcastle; Scott Hanks and Tyler Clark from Quikrete, and Brent Overson from Utah Masonry Council. The following BYU students conducted the work: Jacob Ballard, Robert Godfrey, Zifan Guo, Juan Manuel Salguero Mendizabel, Brice Somers, and Scott Watterson. These students were supported financially by a generous grant from the NCMA Education and Research Foundation.

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