STRENGTH OF MASONRY PRISMS WITH HIGH AMOUNTS OF SUPPLEMENTAL CEMENTITIOUS MATERIALS

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A masonry prism testing scheme was devised to aid in the determination of whether prisms with grouts possessing high levels of supplemental cementitious materials could meet minimum masonry compressive strength requirements. Class F fly ash and ground granulated blast furnace slag replaced portland cement in large incremental amounts in masonry grout to establish higher use limitations. In conjunction with testing prisms, the variations of grout were tested for their respective compressive strength to determine the correlation between masonry compressive strength and grout compressive strength.

Prisms and grouts underwent standardized testing for maximum compressive strength at age intervals of 14, 28, 42, 56, and 90 days. Seven variations of grout were manufactured in three groups. The first, the control group, contained one grout design with no supplemental cementitious materials and had a portland cement content of 100%. The second group replaced portland cement, by weight, with fly ash in amounts of 45%, 55% and 65%. The third group replaced portland cement with 25% fly ash and 40%, 50% and 60% ground granulated blast furnace slag. The fly ash-slag mixture, thus, replaced portland cement at rates of 65%, 75%, and 85%.

Results indicate that all prisms exceeded minimum compressive strength requirements before the 28 day age period. Not all grout types met the ASTM minimum 13.8 MPa (2000 psi) at 28 days. Neither 55% and 65% fly ash replacements nor the 85% fly ash-slag combination achieved grout strength minimums at the specified age. The grout mixtures manufactured with exceeding addition rates which attained greater than allowed strength at the 28 day age were the 45% fly ash and 75% fly ash-slag combination. All grouts did, eventually, extend their strength gain beyond 13.8 MPa (2000 psi) through the course of testing and all but 65% fly ash achieved this strength within 42 days.

Keywords: Masonry, Prisms, Grout, Cementitious Materials, Fly Ash, Slag

INTRODUCTION

Masonry construction has utilized pozzolans and slags in units, mortars, and grouts. The quantity of portland cement replaced by these materials is governed and limited by ASTM Standards in conjunction with the Building Code Requirements and Specification for Masonry Structures (TMS 402-08/ACI 530-08/ASCE 5-08). Fly ash (FA) and ground granulated blast furnace slag (GGBS) provide for economically and environmentally responsible methods of
construction and are deemed sustainable. Extensive information is available for concrete masonry units and mortars that have included pozzolanic and slag materials (Korany 2000 and Producing 2003). Current restrictions on masonry grout are analogous to the limitations placed on concrete. Recognizing that there are differences between these two construction materials and their uses allow for exploration of the boundaries of masonry grout’s portland cement replacement percentage guidelines.

Limited data, commissioned by the Concrete Masonry Association for California and Nevada (CMACN), for grout mixed with greater quantities of fly ash and GGBS than allowed has become available. Refining the outcomes of CMACN’s initial research, researchers at Brigham Young University, designed a broad research program to determine if masonry prisms constructed with high percentage replacement of portland cement grouts with FA and GGBS meet minimum required masonry strengths.

Expanding the limits of portland cement reduction can further brand masonry as a sustainable construction method. Portland cement production generates green-house gas emission while depleting natural resources. FA and GGBS are recycled materials, often more affordable than portland cement, which if not reused end up in landfills and water systems. More extensive use of these supplemental cementitious materials can effectively eliminate waste products and help conservatively utilize available resources without conceding building code requirements. By performing standardized testing, prisms constructed with grouts with large quantities of pozzolanic and slag materials can, as an assemblage, be proven to possess adequate, code compliant, compressive strength. Results can then be interpreted as beneficial to the masonry industry, promoting and branding masonry construction as cost and environment conscious.

FLY ASH AND SLAG
Fly ash is a pozzolan, which is a finely divided siliceous or siliceous and aluminous material which possesses little or no inherent cementitious properties, but in the powdery form and in the presence of moisture, will chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (Wang 2007). Fly ash is a byproduct of the coal industry, termed a waste material, predominantly generated in the production of electricity; Class F fly ash, used in this testing program, is the product of burning bituminous and anthracite class coal (Scheetz 1998). The greatest utilization for fly ash is as an additive to cement and concrete. Benefits stemming from the use of fly ash are a decrease in water demand, improvement in particle size packing, savings of portland cement material resulting in lower costs, corrosion resistance and greater strength (Scheetz 1998). The strength development, however, is not as quick initially as an all-portland cement based grout. Where standards require 28-day strengths, time is of the essence and grout containing fly ash can meet the strength requirement but not the time requirement.

Ground granulated blast furnace slag is increasingly being used to replace some of the cement used in concrete. GGBS is a byproduct of the iron industry, where molten slag from the blast furnace is rapidly cooled and dried to form a granulate which is then ground to a fineness similar to that of portland cement. While this material is no more expensive than portland cement, additional environmental costs are alleviated through the reduction in portland cement’s use of an extensive production process as well as GGBS’s lifespan due to its own durability. Being a cementitious material, it actively adds to the strength gain of the grout and
significant quantities of the portland cement can be exchanged. (Sindel 2007) Due to slag’s small particle size, the workability of grout can be improved with its addition to the grout mix. GGBS cures more slowly and gains strength over longer periods of time which can result in lower initial strengths but higher ultimate strengths. Strength is very much dependent on the GGBS to portland cement proportioning where rate of hydration and ability to hydrate limit GGBS use. Alike to fly ash, a 28-day strength criterion is of issue.

EXPERIMENTAL PROGRAM - OVERVIEW

The Building Code Requirements and Specification for Masonry Structures relies on compressive strength values for design (Building 2008). Determination of compressive strength can be established using the unit strength method or through compression testing of masonry prisms. The specified compressive strength of masonry \( f_m \), as a result of one of these methods, must either exceed or be equal to 10.3 MPa (1,500 psi) but be no greater than 27.6 MPa (4,000 psi) for concrete masonry in order to be used in determining nominal strength values (Building 2008). Utilizing the prism testing method for the determination of \( f_m \), ASTM International specifies that grout for masonry must obtain a minimum compressive strength of 13.8 MPa (2000 psi) at 28 days while other consenting organizations indicate that the specified compressive strength of grout shall exceed or be equal to the compressive strength of masonry while not exceeding 34.5 MPa (5000 psi) (Building 2008 and ASTM). A testing program was conceived involving two stages of experimentation. The first stage involved the manufacturing and testing of grout variations which employ greater use of supplemental cementitious materials than the 40% pozzolan and 70% pozzolan-slag addition rates dictated in grout standards (ASTM). The second stage included compression testing of masonry prisms constructed with the first stage’s grout variations. Correlations between the strength of the grout and the prisms can then be made and the viability of using increased quantities of fly ash and slag in masonry grout is then assessed.

EXPERIMENTAL PROGRAM – GROUT

A standardized grout design was formulated with a target of 27.6 MPa (4000 psi) strength at 28 days. The cementitious material content of the design was modified to form the variations where the total cementitious quantity, by weight, remained constant. Grouts are referred to by type, which are shown in Table 1. Since the weight of the water remained constant, the slump was allowed to fluctuate. As increased supplemental cementitious materials were added, slump increased. The accepted range of slump for masonry grout is between 200 to 280 mm (8 to 11 inches). Grout type 1 had a 228 mm (9 inch) slump. Grout type 4 was the only mix that exceeded slumping limitations and was deemed to be flowable. Maintaining consistency with the water content was considered to be more important to strength outcome comparisons than was slump. Due to the scale of the research, casting was performed by filling the cores of concrete masonry units (CMUs). The CMUs used are of the same batch as those used in the casting of prism. Blocks were of 200 x 200 x 200 mm (8 x 8 x 8 inch) dimensions. All other methods of specimen forming were per ASTM C1019 (ASTM). After 48 hours of curing specimens were removed from their molds and stored in a moist room where they remained until testing. On the day of testing specimens were capped in accordance with ASTM C617 and compression tested as indicated in ASTM C39/39M (ASTM). Figure 1
shows a grout specimen just prior to testing. At minimum three specimens were tested for strength at intervals of 14, 28, 42, 56, and 90 days.

**Table 1: Grout Identification and Cementitious Content**

<table>
<thead>
<tr>
<th>Grout Type #</th>
<th>Cementitious Content</th>
<th>Slag (%)</th>
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<tbody>
<tr>
<td></td>
<td>Portland Cement (%)</td>
<td>Fly Ash (%)</td>
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<tr>
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**Figure 1: Grout Specimen**

In order to correlate the method of testing used in this testing program with that specified in ASTM C1019 a correction factor was established. A grout mix identical to that of grout type 1 was manufactured where 12 specimens were poured filling the cores and 12 specimens were poured into a void created by a 4 prism arranged as specified. A standard specimen is shown in Figure 2 and a core-filled specimen in Figure 1. A multiplicative factor of 1.2 was determined to adjust core-filled specimens to that of a standard specimen.
Data represented in the strength progression plots for both grout and prisms underwent data reduction. Each data point is represented by the average of at least three test specimens. If the results of a compression test were one standard deviation away from the average it was omitted if and only if there were more than three specimens tested. If within a specific test group there were two specimens outside one standard deviation, a single specimen achieving one standard deviation less than the average and a single specimen achieving one standard deviation more than the average, the two were outliers were averaged to create one compressive strength. This discretionary practice of eliminating specimen results helps to remove strengths that are too high or too low of what is represented by the other specimens in the group. The strength differences between each specimen within their respective group are reduced and the single compressive strength value reported is more reliable and representative of the group.

The strength progression of the grout types can be seen in Figure 3 below. Types 1, 2, 5, and 6 meet the ASTM specification of 13.8 MPa (2000 psi) at 28 days while Types 3, 4, and 7 attained satisfactory strengths at later ages. Types 3 and 7, composed of 55% fly ash and 85% fly ash-slag, respectively, are very near to the target strength. Other research has indicated that 50% fly ash and 80% fly ash-slag has reached appropriate strength levels in 28 days (Siggard 2010). Between the 50-55% fly ash and 80-85% fly ash-slag range establishes the masonry grout cementitious supplemental material addition rate boundaries for current strength and age requirements. Inconsistencies in the data lie in 28-day testing of types 5 and 6 where a strength drop can be observed. Inconsistencies could be attributed to materials, testing apparatus, or workmanship. These inconstancies, while present, do not hinder conclusions.
EXPERIMENTAL PROGRAM – PRISMS
Masonry prisms were assembled by professional masons with the components of concrete masonry units, type M mortar, and the grouts previously defined. Two CMUs with one mortar joint either grouted or ungrouted make up a single masonry prism test specimen. Five prisms at each test age and for each grout type were constructed; hollow prisms were also constructed. Prisms were constructed in an opened, moisture-tight bag large enough to enclose and seal the completed prism on a flat and level base. Units were laid in stack bond with full, flush 10 mm (0.375 inch) mortar beds. Specimens were grouted 24 to 48 hours after construction. Upon grouting specimens were permanently sealed in the moisture-tight bag. Prims remained in the moisture tight bags until 48 hours before their respective test age. Prior to compression testing the prisms were capped with gypsum cement in accordance with ASTM C1552 (ASTM). A finished prism is displayed in Figure 4. At minimum, three prisms were tested, at the same intervals as the grout, until failure and until a failure mode was apparent.

Prisms averaged a height-to-thickness ratio of 2.06, which falls between accepted 1.3 to 5.0 ratios (ASTM). The lateral confinement at the tops and bottoms of the prims increases the apparent compressive strength and changes the mode of failure to a shear mode which is not observed for walls or for prisms composed of more courses (Drysdale 1979). While prims specimens do meet minimum height to width ratios for testing, perhaps adhering to the minimum rather than the maximum is not as representative of real construction.

Figure 5 shows the strength progression of the prisms. All prisms reached the strength target prior to the 28 day age period. A majority of specimens showed a slight decrease in strength at 28 and 56 days, while remaining above 10.3 MPa (1,500 psi), which can possibly be attributed to the materials, testing apparatus, or workmanship.
**Figure 4: Prism Specimen**

**Figure 5: Prism Strength Progression**
DISCUSSION AND CONCLUSIONS
Grout mixtures utilizing fly ash and ground granulated blast furnace slag are an excellent way to reduce consumption of portland cement resources. Upon doing so, essentially waste materials can be recycled. Cost savings or equivalency can also be found with their use. Wider adaptation of masonry grouts composed with large quantities of fly ash and slag is possible due to reassurance that research provides.

Up to 45% of portland cement can successfully be replaced with fly ash and up to 75% can be replaced with a combination of fly ash and slag and achieve 13.8 MPa (2,000 psi) strength after a 28-day period determined by this research. The fly ash-slag 75% replacement which proved effective contained 25% fly ash and 50% slag. The compressive strength of masonry requirements with these forms of non-traditional grouts were unaffected by lower strength grouts. At an early age, all prisms attain and continue to gain strength well over the 10.3 MPa (1,500 psi). Limitations are isolated to the initial strength gain at 28 days. Since the grouts used experimentally herein gain strength more slowly than that of an all portland cement mixture, it is reasonable to extend the time at which strength minimums must occur to get the most benefit from increased use of pozzolans and slags. When construction, rather than standards, permits for longer durations of grout curing, greater replacement of portland cement could be incorporated into the design. For instance, waiting an addition 14 days to achieve a 13.8 MPa (2,000 psi) 42-day strength minimum allows up to 55% of portland cement to be replaced by fly ash and up to 85% to be replaced by a combination of fly ash and slag.

The material limitation of a region will affect the strength outcome of both masonry prisms and grouts. Greater reliance on the prism test method can further the adoption of high replacement grouts by proving adequate strength. Within the ranges of 50-55% fly ash and 80-85% fly ash-slag are the addition rate boundaries for masonry grout. Perhaps with further research on the addition rates while maintaining a constant slump rather than a constant water content could these boundaries be further extended. In order to achieve acceptance of the notion of relaxing the age criterion for high replacement grout strength gain, further exploration of the boundaries of maximum portland cement replacement must occur.

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