PERFORMANCE OF NO VIBRATION / NO ADMIXTURE MASONRY GROUT CONTAINING HIGH REPLACEMENT OF PORTLAND CEMENT WITH FLY ASH AND GROUND GRANULATED BLAST FURNACE SLAG

James P. Mwangi[1], Eric W. Bateman[2] and Craig Baltimore[3]

[1] Ph.D., S.E., Associate Professor, Architectural Eng. Dept., California Polytechnic State University – San Luis Obispo, California, 93407, USA, jmwangi@calpoly.edu

[2] Graduate Student, Architectural Eng. Dept., California Polytechnic State University – San Luis Obispo, California, 93407, USA, ebateman@calpoly.edu

[3] Ph.D., S.E., Professor, Architectural Eng. Dept., California Polytechnic State University – San Luis Obispo, California, 93407, USA, cbaltimo@calpoly.edu

ABSTRACT

When hollow concrete masonry is used for construction in high seismic regions, structural designs typically require fully grouted walls. For a fully grouted 200x200x400 mm (8x8x16 in.) concrete masonry unit (CMU), 52 percent of total volume is grout. Grouting process is labor-intensive, time consuming and has a high energy demand due to requirements of consolidation in each and subsequent grout lifts. Self-consolidating grout with admixtures has been successfully used without segregation in wall lifts of up to 3.86 m (12.67 ft.) in height. The admixtures used in these grouts are very sensitive to the chemistry of the mix and the sensitivity can be an issue for performance consistency. Eliminating the proprietary admixture from the mix design can have benefits. Sustainable grout where cement is replaced with fly ash and/or blast slag has self-consolidating grout flow properties. This paper investigates sustainable self-consolidating grout mixes without admixtures.

This paper reports on the investigation of compression strength and gives general consolidation observations of self-consolidating characteristics of no vibration/no admixture grout made by substituting various proportions of Portland cement with Type F fly ash and/or ground granulated blast furnace slag (GGBFS). The percentages of Portland cement replacement were 0%, 50%, 60%, and 70% for Type F fly ash and 0%, 60%, 70% and 80% for Type F fly ash and GGBFS.

Compression test specimens were made from individual 200x200x400 mm (8x8x16 in.) concrete masonry hollow core units and dry cured at 7, 14, 28, 42, and 56. Compression test specimens for 130 days dry cured period where cut from testing walls. Consolidation testing specimen walls were built to a height of 3.86 m (12.67 ft.) and 1.22 m (4.0 ft.) length using 200x200x400 mm (8x8x16 in.) CMU. The relative performance was assessed by comparing to traditional grouted masonry and evaluating consolidation characteristics around mortar fins and reinforcement at 130 days as well as compressive strength of the grout at various wall heights.

KEYWORDS: self-consolidating grout, conventional grout

INTRODUCTION

In the manufacturing process for cement, sixty percent of the carbon dioxide production is due to a chemical process [1]. Many researchers have attempted to reduce the carbon dioxide emissions from the chemical process but there have not been viable solutions [2]. Therefore, the short time goal should be to reduce the amount of cement in products. Fly ash is an industrial waste material that comes from the combustion of coal. Blast furnace slag is a by-product of iron and steel production. Fly ash and slag can cause severe environmental problems if not disposed of correctly. The utilization of fly ash and slag in concrete and grout instead of dumping the waste material in landfills is a solution to properly dispose of these materials in a sustainable way.

Grout, like concrete, is a cementitious material, typically used in hollow concrete masonry construction. In high seismic regions, structural designs require fully grouted walls. The volume of grout in a fully grouted 200x200x400 mm (8x8x16 in.) concrete masonry unit (CMU) is approximately fifty two percent of the total volume. Since large amounts of grout are required, a more sustainable grout mixture would benefit the environment. Using Type F fly ash and/or slag as a partial replacement of Portland cement, the amount of cement in grout would be reduced. The replacement of cement with fly ash and/or blast slag has increased flowability allowing for a natural potential (no admixtures) of self consolidation.

Self-consolidating grout is a highly flowable grout that can spread into place under its own weight and achieve consolidation with no air pockets, limited segregation of materials in the grout, and a full connection between the concrete masonry, grout, and reinforcement [3]. The pozzolanic reaction resulting when fly ash and slag are used will require a longer cure time to fully develop the strength of the grout mixture. High fly ash and slag replacement of cement in grout would increase the flowability and could potentially satisfy the strength requirements of grout while retaining even limited segregation and air voids in order to be classified as a self-consolidating grout.

Self-consolidating grout in concrete masonry construction also has important economic benefits; for the labor of mechanical consolidation is eliminated and high lifts can be used. Also, a mechanical vibrator is difficult to properly operate in high reinforcement regions due to tight spacing. Self-consolidating grout allows for consolidation without additional vibrations, saving time and money.

This paper presents an investigation of the suitability of high replacement of cement in grout with Type F fly ash and/or ground granulated blast furnace slag (GGBFS), without the use of admixtures, for the grout to function as self-consolidating grout. Self-consolidating grout with Type F fly ash and/or slag replacement can provide higher sustainability in masonry construction and also has important economic benefits. Limiting the cement needed in grout would lower the demand for cement and in turn its production. By decreasing production of cement, the required energy from fossil fuels would also decrease. Also, by replacing the cement with a recycled material, such as fly ash and slag, no additional energy would need to be produced. Using recycled materials and reducing the need for fossil fuel would promote sustainability.

LITERATURE REVIEW

Grout is required to flow into all areas of the highly reinforced masonry wall to bond the reinforcement and masonry units together. For conventional grout, a mechanical vibrator is required for consolidation to eliminate air voids and to help ensure sufficient bond strength between materials. The vibrator may be difficult to get into small spaces because of the closely spaced reinforcement [4]. Another feature of conventional grouting is applying the grout at different lifts. A low lift is approximately 1.2 m (4.0 ft) high and a high lift is approximately 3.66 m (12.0 ft) high [4]. A low lift normally contains less error of consolidation than a high lift when using a mechanical vibrator, but it takes several low lifts to reach the height of the high lift. Each lift must be consolidated before the next lift is placed, which takes more time. For high lifts, consolidation is harder to achieve, so the labor requires a higher trained worker. The processes of vibrating and repeated lifts are labor-intensive and time consuming which increase costs.

Proper consolidation in grout means no air voids, no segregation, and an adequate bond between the concrete masonry, grout, and reinforcement. Greenwald, et al, [5], compared the consolidation of self-consolidating grout with admixtures to conventional grout through experimentation. Grouted wall specimens were cut at the top, middle, and bottom portions of a fully grouted concrete masonry wall 3.86 m (12.67 ft.) tall. The specimens were compared on air voids, segregation, and the grout's bond to the reinforcement through visual inspection. There were no significant differences between the self-consolidating grout and the conventional grout. Similar experimental studies have been reported by Horta [6] and also by Hodgson, et al [7] using self-consolidating grout with fly ash. Bradfield [8] reported on the compressive strength of high replacement cement in grout using fly ash and slag. Experimental procedural techniques similar to Bradfield's [8] were used in this investigation on comparing consolidation and compressive strength of grout. This paper focuses on comparing the consolidation of self-consolidating grout with Type F fly ash and/or slag replacement and conventional grout, through visual inspection. Compressive strengths of grout specimens were determined at various curing time periods.

TEST PROGRAM

Two experiments were conducted to investigate if high Portland cement replacement grout could be characterized as self-consolidating grout. The experimental grout mixtures used fly ash or fly ash and GGBFS as the replacements for Portland cement, with no admixtures added. These grouts were compared to a baseline grout mixture (conventional grout: no Portland cement replacement). The same grout mixtures were used for both experiments.

The first experiment, The Compression Experiment, investigated the performance of the potential self-consolidating grouts through compressive strengths of individually grouted CMU at various curing times. The second experiment, The Wall Experiment, investigated the behavior and performance of the potential self-consolidating grouts throughout the height of a high lift wall assembly through visual assessment and physical evaluation. Specifically, the investigation focused on three different aspects of consolidation by comparing the potential self-consolidating grouts to conventional grouted masonry: a visual inspection of the flow characteristics around the mortar fins and reinforcement in the CMU cells, an evaluation of compressive strength at one time in the curing process, and an evaluation of the bond between the reinforcements and grouts.

All tests were conducted at the High Bay Laboratory and Concrete Laboratory in the Architectural Engineering department of the College of Architecture and Environmental Design at the California Polytechnic State University in San Luis Obispo, California.

Materials used in the study were:

- Portland cement Type II-IV complying with ASTM C150
- Coal fly ash Class F complying to ASTM C618
- Ground granulated blast furnace slag (GGBFS) Grade 100 complying with ASTM C989
- Type S masonry mortar complying with ASTM C270
- Hollow concrete masonry units (CMUs) complying with ASTM C90
- Coarse aggregate 9.5 mm (3/8-in.) pea gravel complying with ASTM C404
- Washed concrete sand complying with ASTM C404
- Steel reinforcement complying with ASTM A615
- Potable water

Trial grout proportions, by volume, followed the upper bound on aggregates as specified by ASTM C476. No admixtures were added to any of the grout mixtures. The only factor in the grout proportions that changed between each mixture was within the cementitious materials. There were three types of cementitious material experimented with: no replacement of Portland cement, Type F fly ash replacement of Portland cement, and Type F fly ash and GGBFS replacement of Portland cement. The no-replacement grout referred to as conventional grout or the "base mix design" represented the cementitious type of grout that is most commonly used in industry, which requires vibration for consolidation, and which the other grout mixtures were been compared to. There were three grout mixtures within both the fly ash replacements and fly ash and GGBFS replacements. The proportions for cementitious material for the fly ash and/or GGBFS replacement were as shown in Table 1 (next page).

Table 1: Proportions of Fly Ash and GGBFS Replacement of Cement in Experimental Mixtures

Type F Fly Ash and GGBFS Replacements		
Test Name	Cementitious Material	

	Cement (% Vol.)	Fly Ash (% Vol.)	GGBFS (% Vol.)	Description
50F	50	50	0	50% Fly Ash Replacement
60F	40	60	0	60% Fly Ash Replacement
70F	30	70	0	70% Fly Ash Replacement
60SF	40	15	45	60% Fly Ash & GGBFS Replacement
70SF	30	17.5	52.5	70% Fly Ash & GGBFS Replacement
80SF	20	20	60	80% Fly Ash & GGBFS Replacement
100C	100	0	0	Conventional Designed

In order to comply with ASTM C476, the "base mix design", was determined to have a water-to-cement ratio of 1.375 (by volume), which provided a slump between 249 to 254 mm (9.5 to 10 in.), as determined following ASTM C143. The water-to-cementitious materials ratio was kept constant at 1.375 (by volume) for all of the grout mixtures. According to ASTM C476, in order for the grout mixtures to qualify as self-consolidating, the grout mixtures needed to provide a slump flow of 610 to 762 mm (24 to 30 in.) (determined by ASTM C1611), have a Visual Stability Index (VSI) of not greater than 1 (determined by Appendix XI of ASTM C1611), and have a minimum compressive strength of 13.8 MPa (2000 psi) at 28 days of curing (in accordance with ASTM C1019). An example of slump flow can be seen below in Figure 1.

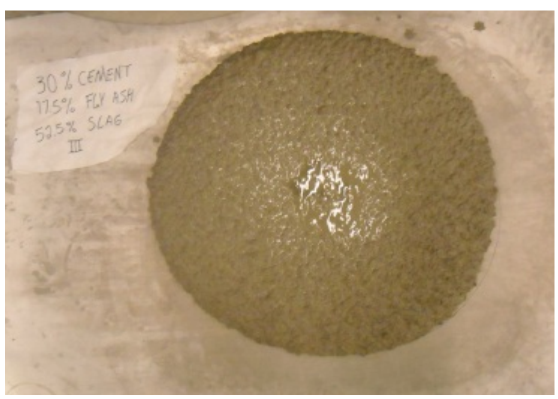

Figure 1: Slump Flow Picture of 70SF Batch 3

The Compression Experiment determined the compressive strength of the various grout mixtures. All seven grout mixtures were proportioned as shown in Table 1. The grout samples were dry cured within the cells of 200x200x400 mm (8x8x16 in.) CMUs. Three samples per mixture were tested at 7, 14, 28, 42, 56, and 130 days of curing. The number of grout specimens used in this investigation for each curing process is shown in Table 2.

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

Number of Grout Test Specimens for Each Curing Process									
Test Name	Cementitious Material			Test Age (Days)					
				7	14	28	42	56	130
	Cement (% Vol.)	Fly Ash (% Vol.)	GGBFS (% Vol.)	Number of Specimens					
100C	100	0	0	3	3	3	3	3	3
50F	50	50	0	3	3	3	3	3	3
60F	40	60	0	3	3	3	3	3	3
70F	30	70	0	3	3	3	3	3	3
60SF	40	15	45	3	3	3	3	3	3
70SF	30	17.5	52.5	3	3	3	3	3	3
80SF	20	20	60	3	3	3	3	3	3
Total Number of Specimens = 126									

The material proportions were batched by volume and mixed in a mechanical mixer in accordance with ASTM C476 as seen in Figure 2.

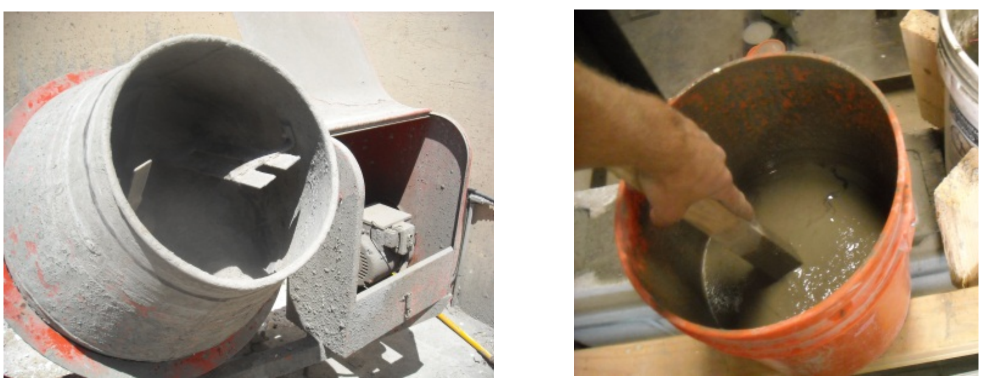

Figure 2: Grout Materials Mixing in (a) Mechanical Mixer and (b) Re-Mixing in Bucket

Grout specimens were made and tested in accordance with ASTM C1019, with one exception: the grout was poured into the cores of 200x200x400 mm (8x8x16 in.) rather than constructing a grout mold using four CMUs. This exception was made in order to save space and mimic the same water absorption the grout experiences while curing in the core of the CMU, yet still providing the absorptive mold requirement in ASTM C1019. The grouted CMUs were dry cured, complying with ASTM C157, as seen in Figure 3.

Figure 3: (a) Placing Grout into Cores of CMUs and (b) Dry Curing Grout Specimens

After curing and one day prior to testing, the compression test specimens were made by saw cutting the grout specimens to 102x102x203 mm (4x4x8 in.), satisfying the dimensional requirements of ASTM C1019 as shown in Figure 4.

Figure 4: (a) Wet Saw Cutting Specimens and (b) Final Grout Compression Specimens

The specimens were capped and tested in compression in accordance with ASTM C1019 as shown in Figure 5 (next page).

Figure 5: (a) Capping of Grout Compression Specimens and (b) Compression Testing

Four walls were constructed by professional masons in one lift for the Wall Experiment. All the walls were built in running bond using double square core, single wythe 200x200x400 mm (8x8x16 in.) CMU, and 19 courses high for a total height of 3.86 m (12.67 ft). Full mortar bedding was used to prevent the grout from flowing into adjacent grout columns. The walls were labeled 1, 2, 3, and 4. Walls 1, 2, and 3 were used for the evaluation of compression strengths and visual inspection of the flow characteristics around the mortar fins and reinforcement of the grouts at varying heights along the wall. Wall 4 was used for the evaluation of the bond between the reinforcement and grouts at varying heights along the wall. Walls 1, 2, and 3 were 1.2 m (4.0 ft) wide and consisted of six grout columns. The walls had two 16 mm (#5) horizontal reinforcement bars placed at 0.61 m (2.0 ft) on center vertically. Wall 4 was 1.63 m (5.33 ft) wide and consisted of eight grout columns. The wall had one 10 mm (#3) vertical reinforcing bar placed as close to the middle of each grout column as possible, throughout the entire height of the column as shown in Figure 6.

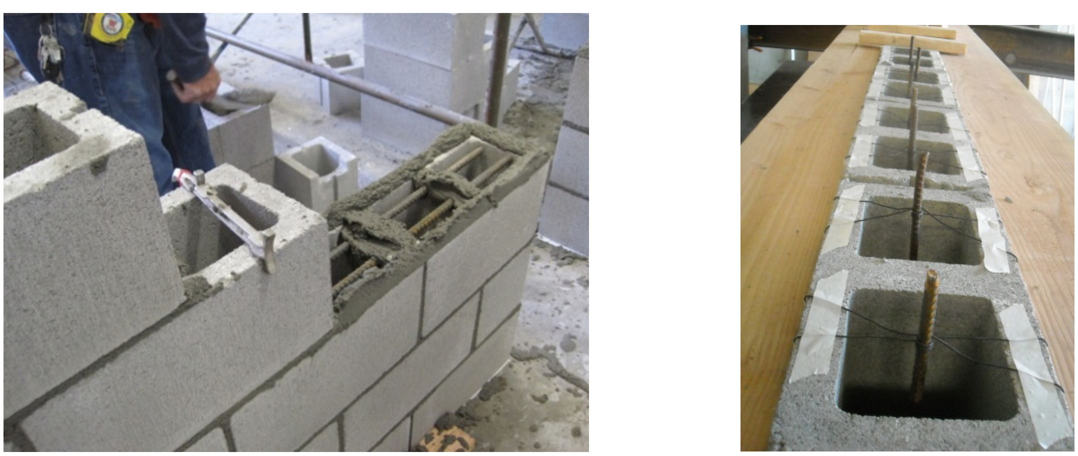

Figure 6: Wall Construction (a) Horizonal Steel Placement and (b) Vertical Steel Placement

Cleanouts were provided at the bottom of the walls in the first course of all the columns to be grouted as shown in Figure 7.

Figure 7: (a) Wall Elevation and (b) Location of Cleanouts at Bottom of Wall

A different type of grout was placed in each of the four walls as shown in Table 3 (next page). Fly ash replacement grouts were used in wall 1, fly ash and GGBFS replacement grouts used in wall 2, conventional grout used in wall 3 and all grouts used in wall 4. For walls 1, 2, and 3, each mixture of grout was used in two grout columns. For wall 3, three grout columns were vibrated and two were not.

Table 3: Grout Column Composition and Identification in Walls

Grout Column Composition									
Wall	Column	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8
1	Grout	50F	50F	60F	60F	70F	70F		
	Col. ID	1-1-1	1-1-2	1-2-1	1-2-2	1-3-1	1-3-2		
	Vibrated	No	No	No	No	No	No		
2	Grout	60SF	60SF	70SF	70SF	80SF	80SF		
	Col. ID	2-1-1	2-1-2	2-2-1	2-2-2	2-3-1	2-3-2		
	Vibrated	No	No	No	No	No	No		
3	Grout	100C	100C	100C	100C	100C			
	Col. ID	3-1-1	3-1-2	3-1-3	3-2-1	3-2-2			
	Vibrated	Yes	Yes	Yes	No	No			
4	Grout	100C	100C	50F	60F	70F	60SF	70SF	80SF
	Col. ID	4-1-1	4-2-1	4-3-1	4-4-1	4-5-1	4-6-1	4-7-1	4-8-1
	Vibrated	Yes	No	No	No	No	No	No	No

The walls were grouted between 77 and 81 days after the walls were erected. The materials were batched by volume and mixed in a mechanical mixer in accordance with ASTM C476 as shown in Figure 2. The slump test, following ASTM C1019, was conducted for the conventional grouts or a slump flow test, following ASTM C1611, was conducted for the experimental grouts. The grout was poured into the grout column through a funnel at the top. A flashlight was used to check if there was any seepage of the grout into the adjacent grout columns and none was observed in all columns. For the conventional grout columns with mechanical consolidation, the mechanical internal-type vibrator was lowered into the center and all the way to the bottom of the column before the grout was poured. Once approximately one third of the grout column height was filled with grout, the vibrator was turned on and left for 5 seconds and slowly lifted out one third of the way. This was repeated until the grout column was completely grouted and vibrated. Figure 8 shows the grouting and vibration operations.

Figure 8: (a) Grout Funnel Leading into One Grout Column and (b) Mechanical Vibration

The walls were lowered to a horizontal position approximately 70 days after being grouted using an overhead crane as shown in Figure 9.

Figure 9: (a) Lowering the Wall and (b) Lowered Walls

For Walls 1, 2, and 3, there were six different heights along the wall where both the compression test specimens and consolidating inspections were taken. The location of each specimen was identified by a 3-digit grout column ID code from Table 3 with an added marker at the end to indicate the height along the column where that specimen came from. For compression specimens, the last markers were numbers that varied from 1 to 6, 1 being the closest to the bottom of the wall and 6 being the closest to the top of the wall. The compression test specimens were taken at heights of 0.3, 0.91, 1.52, 2.13, 2.74, 3.35 m (12, 36, 60, 84, 108, 132 in.) from the bottom of the wall. For the consolidation specimens, letters in alphabetical order from A to F, A starting closest to the bottom of the wall and F nearest the top were used. The consolidation specimens were taken at heights of 0.51, 1.12, 1.73, 2.34, 2.95, 3.56 m (20, 44, 68, 92, 116, 140 in.) from the bottom of the wall.

For Wall 4, there were three different heights along the wall where rebar pullout specimens were taken. The last digit was number 1 for specimens taken at 0.41 m (16 in.), 2 for specimens taken at 1.63 m (64 in.), and 3 for specimens taken at 3.25 m (128 in.) from the bottom of the wall.

The walls were cut by a demolition company using 355.6, 406.4 and 457.2 mm (14, 16 and 18 in.) diameter diamond blades and hydraulic ring saws in order to retrieve the test specimens. The walls were cut horizontally and vertically as shown in Figure 10 (next page).

Figure 10: Cutting Walls (a) Horizontally and (b) Vertically

A 508 mm (20 in.) diamond blade wet saw was used to cut the compression specimens into 102x102x203 mm (4x4x8 in.) grout units as shown in Figure 4 and the consolidation specimens were cut once across the middle of the grout cell in order to see the consolidation characteristic around the reinforcement. In total, 96 compression test specimens and 96 consolidation specimens were retrieved from the walls. Figure 11 shows wall compression and consolidation specimens.

Figure 11: (a), (b), Side of Compression Specimen and (c) Consolidation Specimen with Steel Reinforcement

The retrieved compression specimens were capped and prepared for testing in accordance with ASTM C1552 and ASTM C1314, as shown in Figure 5.

For wall 4, grout in each section was chiseled away from the reinforcement in order to prepare specimens for rebar pull out test.

TEST RESULTS AND DISCUSSION

The experimental grouts were found to have a slump flow between 610 to 762 mm (24 to 30 inches) for all of the mixtures as determined following ASTM C1611, therefore, satisfying one of the requirements to be considered a self-consolidating grout. For both types of cement replacement, it was found that, in general, the slump flow increased in diameter as the amount of cement in the mixture decreased. All experimental grouts were found to have VSI of 1 (Stable) as there was no evidence of segregation but a slight bleeding was observed as a sheen on the grout mass. None of the mixtures were considered unstable because there was no noticeable mortar halo and/or aggregate pile in the center of the grout mass. Having a VSI of 1 satisfies another requirement of ASTM C476 for the experimental grouts to be considered a self-consolidating grout.

Compression test results for the experimental and conventional grouts are shown in Figure 12.

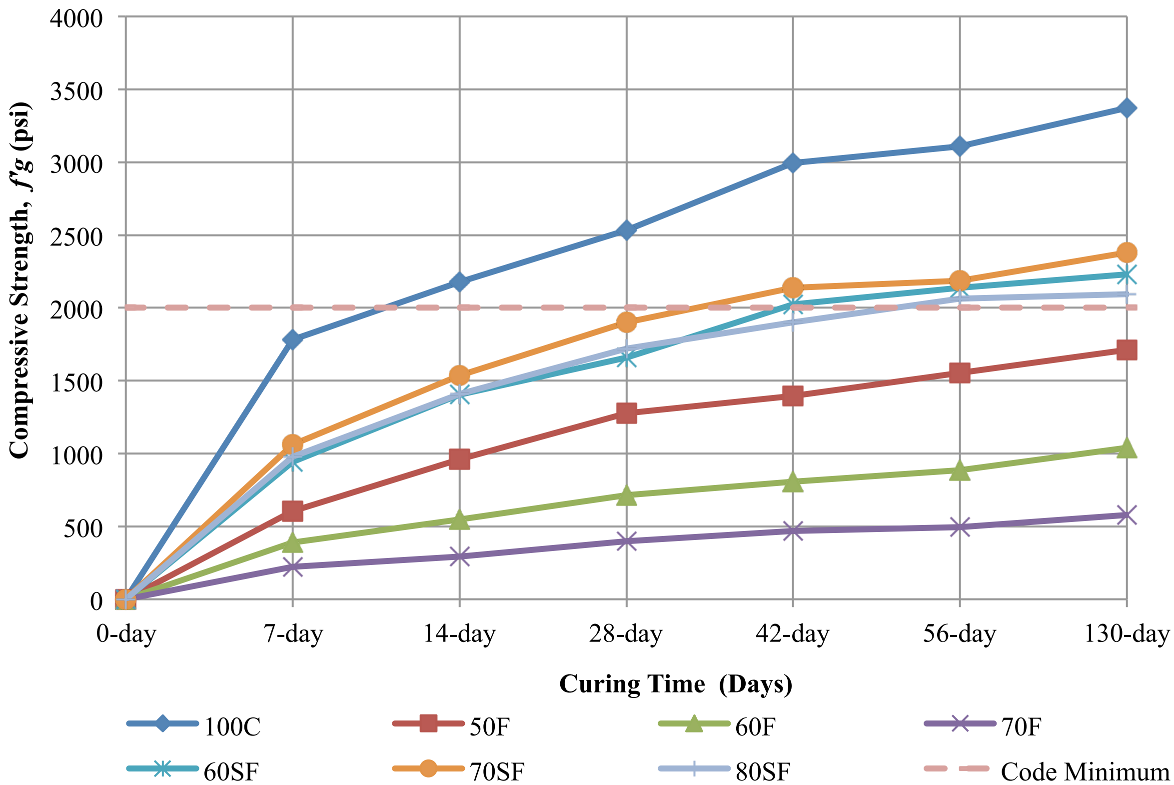

Figure 12: Average Net Corrected Compressive Strength of Grouts

Compression tests on the wall specimens were conducted 130 days into the curing process. The average compressive strengths (over entire wall height) of the wall grout columns are shown in Figure 13.

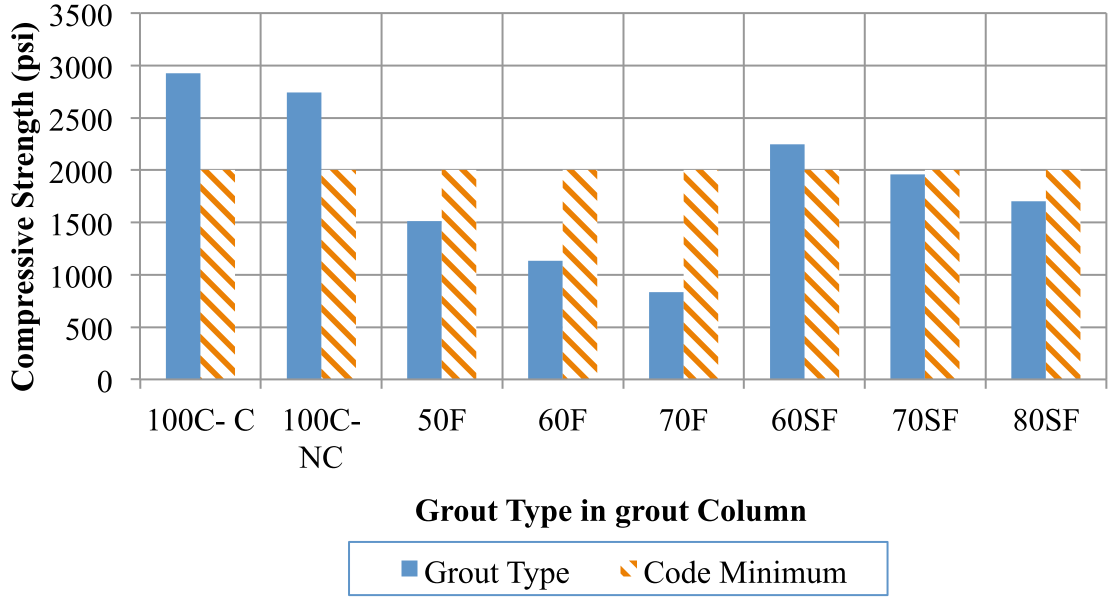

Figure 13: Average Net Corrected Compressive Strength of Grouts from Wall Grout Columns After 130 Days of Curing

From the visual observations, all grout mixtures provided consolidation without segregation of grout ingredients over the entire height of the grout columns. The reinforcement where provided was observed to have had proper cover of grout all around the reinforcement. The grout was also observed to have fully filled the gaps around the mortar fins.

CONCLUSION

The investigated grout mixtures using replacement of fly ash and/or GGBFS can be classified as non-consolidated grout. The grout mixtures where Portland cement was replaced with Type F fly ash and GGBFS reached the code prescribed minimum strength after 56 days of curing. The same results were obtained when the wall samples were tested at 130 days where 60% replacement of fly ash and GGBFS was used. Grouts with only fly ash replacement do not meet the code required strengths after 56 days of curing. The results on the compression test specimens from both experiments (Compression and Wall) produced the same results. The wall grout column compression specimens gave larger compression strengths for the samples obtained closer to the bottom of the walls due to the better compaction of the self-consolidating grout due to the weight of grout above that level. This was especially the case there only fly ash was used as the replacement. Compaction around mortar fins and reinforcement was observed to be adequate over the entire height of the walls.

ACKNOWLEDGEMENTS

The following organizations have supported this study and without their monetary, material and labor contributions, this test program would not have been possible: Concrete Masonry Association of California and Nevada (CMACN), Masonry Institute of America (MIA), Pacific Coast Building Products, Basalite Concrete Products, Bricklayers & Allied Craftworkers Local Union No. 4 and Coastal Demo Inc.

REFERENCES

1. Mwangi, J. and Craig, B. (2009) “Going Green with Concrete Masonry Grout.” Summer/Fall Masonry Chronicles, Concrete Masonry Association of California and Nevada.
2. Huntzinger, D., Gierke, J., Kawatra, K., Eisele, T. and Sutter, L. (2009) “Carbon Dioxide Sequestration in Cement Kiln Dust through Mineral Carbonation.” Environmental Science & Technology. Vol. 43: 6.
3. Bonen, D. and Shah, S. (2005) “Fresh and Hardened Properties of Self-Consolidating Concrete.” Progress in Structural Engineering and Materials. Vol. 7.1: 14-26.
4. Khayat, K.H. (1999) “Workability, Testing, and Performance of Self-Consolidating Concrete.” ACI Materials Journal. 96-M43.
5. Greenwald, J., Breeding, D.L., Luttrell, M.D., Ross, D.H., Carter, C.C. and Rouhani. E. (2006) “Self-Consolidating Grout Investigation: Compressive Strength, Shear Bond, Consolidation and Flow.” National Concrete Masonry Association. 04-355.
6. Horta, A. (2005) “Evaluation of Self-Consolidating Concrete for Bridge Structure Applications”. MS Thesis. Georgia Institute of Technology, Atlanta.
7. Hodgson, D., Schindler, A., Brown, D. and Stroup-Gardiner, M. (2004) “The Feasibility of Using Self-Consolidating Concrete (SCC) in Dilled Shaft Applications”. Transportation Research Board.
8. Bradfield, M. (2010-11) “High Supplemental Cementitous Material (SCM) Grout Phase 2 and 3 Research.” Winter Masonry Chronicles, Concrete Masonry Association of California and Nevada.
9. American Society for Testing and Materials. ASTM Standards, ASTM International:
   - A615, Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete reinforcement, 2009.
   - C90, Standard Specification for Loadbearing Concrete Masonry Units, 2009.
   - C143, Standard Test Method for Slump of Hydraulic-Cement Concrete, 2010.
   - C150, Standard Specification for Portland Cement, 2009.
   - C157, Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete, 2008.
   - C270, Standard Specification for Mortar for Unit Masonry, 2008.
   - C404, Standard Specification for Aggregates for Masonry Grout, 2007.
   - C476, Standard Specifications for Grout Masonry, 2010.
   - C618, Standard Specification for 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, 2011.
   - C1314, Standard Test Method for Compressive Strength of Masonry Prisms, 2010.
   - C1552, Standard Practice for Capping Concrete Masonry Units, Related Units and Masonry Prisms for Compression Testing, 2009.
   - C1611, Standard Test Method of Slump Flow of Self-Consolidating Grout, 2009.