Investigation of Grout -

A Comparison of Standard Grout Mix to Self-Consolidating Grout Mix

for:
DR. CRAIG BALTIMORE
(ARCE 598: GRADUATE RESEARCH)

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1.0 PURPOSE

Masonry is a major structural material for low rise buildings, however the design of masonry buildings is rarely taught as a formal course at most universities. As part of the educational experience and to become familiar with the specifications and testing procedures for grouted masonry, a student run experiment on varying the water to cement ratio of masonry grout was conducted. The purpose is to report on the effects of changing the water-to-cement (W/C) ratios in a standard grout mix. The typical W/C ratio is approximately 0.80:1.00. In order to show the effects of increasing water in a grout mix, a second grout mix was investigated – a 1.00:1.00 W/C ratio. The two W/C ratios investigated were a 0.74:1.00 and a 1.00:1.00 W/C ratio. Students prepared and tested the 0.74:1.00 grout mix per the standard of the American Society of Testing and Materials (ASTM) Standard C476 Table 01: Conventional Grout Proportions by Volume, and the ASTM Standard C1019: Standard Test Method for Sampling and Testing Grout.

2.0 INTRODUCTION

In order to achieve the purpose of educating the students, while providing valid ASTM comparison tests, all necessary steps of the process are included in this report. In bullet form the steps are

- Derivation of Standard Grout Mix Design
- Mix Process
- Slump test for 0.74:1.00 Standard Grout Mix
- Slump flow test for 1.00:1.00 Grout Mix
- Curing processes
- Cutting Prisms out of the CMU blocks & Final Curing Stages
- Capping and Testing of Prisms
- What we learned

The introduction section will discuss the derivation of the standard grout mix design and the mix process. The background section discusses how the adding excess water changes the characteristics of a standard grout to a self-consolidating grout. The background section also describes the different types of prisms per American Standard Testing Method (ASTM) C1314. The majority of the report is in the Experimental sections, with the final section containing results from the testing and lessons learned.

2.1 Derivation of Standard Grout Mix Design

The grout mix design was per the American Standard Testing Method (ASTM) C476 *Standard Specification for Grout for Masonry*. Per the standard, the slump must range from 8.0 inches to 11.0 inches. The mix design had a W/C of 0.74:1.00 to produce an 8.25 inch slump. Only the water was increased in this mix design to produce the 1.00:1.00 mix design. ASTM C476, Table 01 C*onventional Grout Proportions by Volume* was used to calculate the proportions in the grout mix design. The mix design in the report is based on weight. However, the code gives guidance in terms of volume. The densities used in conversion of volume to weight are given in Table 01. The conversion of the ASTM specified volumes to weights used in measuring the components of the mix design are shown in Table 02; the mix designs of each W/C ratio are outlined in Table 03.

Table 01: Conventional Grout Parts by Volume – ASTM C476

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TABLE 1 Conventional Grout Proportions by Volume

Type	Parts by Volume of Portland Cement or Blended Cement	Parts by Volume of Hydrated Lime or Lime Putty	Aggregate, Measured in a Damp, Loose Condition	
			Fine	Coarse
Fine grout	1	0–1⁄10	2¼ –3 times the sum of the volumes of the cementitious materials	. . .
Coarse grout	1	0–1⁄10	2¼ –3 times the sum of the volumes of the cementitious materials	1–2 times the sum of the volumes of the cementitious materials

Table 02: Conversion From Specific Parts to Weights based on ASTM C476

	Parts	Volume (ft^3)	Densities (lbs/ft^3)	Weights (lbs)
Cement	(1.00 units)	0.17	78.00	15.00
Water	(0.80 units) ESTIMATED	0.19	62.40	12.00
Washed Sand	(2.67 units)	0.50	90.00	40.00
Pea Gravel	(1.20 units)	0.20	111.00	18.00
Lime	(0.03 units)	NEGLIGIBLE	NEGLIGIBLE	00.50

Table 03 shows that slump tests were performed for grout mixes one and two – the 0.74:1.00 W/C ratio. A slump flow test was performed for grout mix three – the 1.00:1.00 W/C ratio. Slump and slump flow tests describe the viscosity of a mix. Viscosity describes the water content within a mixture. A standard grout mixture with 0.74:1.00 W/C ratio will form a slump when a slump test is performed – the height of the slump is measured. The increased water content in the 1.00:1.00 W/C ratio mix results in a large spreading of the mix – the diameter of the spreading is measured.

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Table 03: Specified Standard Mixes

Grout Mix #1 W/C = 0.74 ; slump = 8.25 inches		
Material	Total Quantity (lbs)	Parts by Volume
Cement	22.52	1.00
Pea Gravel Aggregate	26.84	1.20
Washed Sand	60.02	2.67
Total Water Amount **	16.48	0.74
Grout Mix #2 W/C = 0.74 ; slump = 8.00 inches		
Material	Total Quantity (lbs)	Parts by Volume
Cement	20.68	1.00
Pea Gravel Aggregate	25.10	1.20
Washed Sand	58.33	2.67
Total Water Amount **	15.23	0.74

Grout Mix #3 W/C = 1.00 ; slump flow = 34.38 inches [Visual Stability Index – 0: no evidence of segregation or bleeding]		
Material	Total Quantity (lbs)	Parts by Volume
Cement	44.01	1.00
Pea Gravel Aggregate	52.82	1.20
Washed Sand	65.59	2.67
Total Water Amount	44.57	1.00

** Total Water Amount refers to the water within the mix (including water from aggregates & sand)

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3.0 BACKGROUND

The background section will discuss the importance of the following topics:

- Consolidation in concrete masonry unit (CMU) construction
- How adding excess water changes the characteristics of a standard grout to a self-consolidating grout
- The different types of prisms per American Standard Testing Method (ASTM) C1314

3.1 Consolidation in Grout

Grout is engineered as a structural component in concrete masonry unit (CMU) wall construction: it secures the reinforcement steel (rebar) in place and bonds the rebar to the CMU blocks. The effectiveness of this bond depends on the distribution of the aggregates and sands throughout the grout mixture – this is referred to as the distribution matrix. If the grout is surrounding the rebar on all surfaces and filling in all the voids of the cells within a wall with the aggregate uniformly distributed so that there are no voids the grout becomes consolidated. A typical technique used to help consolidate a grout mixture within a CMU wall is vibration.

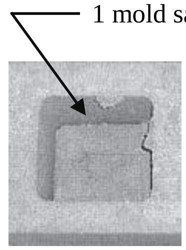
3.2 Water to Cement Ratio in Grout

A typical water to cement ratio used in standard grout mixtures is estimated around 0.80:1.00. When you adjust this W/C ratio there are detriments and benefits as a result of adjusting the W/C ratio. A grout mixture that has a W/C ratio of 1.00:1.00 will have decreased strength (IMI 2009). While the 1.00:1.00 W/C ratio grout mixture has a decrease in strength, the high water content provides fluidity and pumpability in the mixture. The fluidity allows grout to completely fill voids within the wall and surround the steel reinforcement. This additional water changes the characteristic of the grout mixture to a self-consolidating grout mixture. In order to assess the characteristics of a grout mixture a slump test is performed after mixing where the slump must be within 8 inch - 10 inches, shown in Figures 03 - 04. If the grout mixture has a W/C ratio of 1.00:1.00 the grout is highly fluid and a slump flow test is performed to assess the spread of the grout.

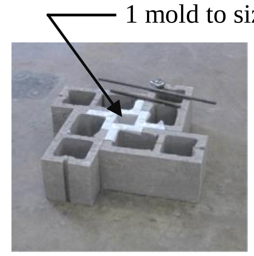
3.3 Grout Prism Testing

For concrete masonry unit (CMU) construction there is a specified compressive strength of grout required by the building code for masonry structures (TMS 402-13) and the American Standard Testing Method (ASTM) C476 *Standard Specification for Grout for Masonry*. In the building code for masonry structures, there is a compressive strength requirement found in section 9.1.9.1 *Compressive Strength* of TMS 402-13 – the compressive strength of masonry shall equal or exceed 1,500 psi and shall not exceed 4,000 psi. In order to determine the compressive strength of grout, there are two methods – prescriptive code methods and grout prism testing. There are three ways to construct the grout prisms which include: cardboard box molds which hold four molds to size, CMU cell molds, and pin wheels. The different grout prism methods are shown in Figure 01.

Cardboard Box Mold



CMU Cell Molds



Pinwheel

Figure 01: Grout Prism Method Types

4.0 EXPERIMENT

This section provides information on the equipment used, location of experiment, and a description for the experimental procedures listed below:

- Mix process
- Slump test for 0.74:1.00 standard grout mixture
- Slump flow test for 1.00:1.00 self-consolidating grout mixture
- Curing process
- Cutting prisms and final curing stages
- Capping and testing of prisms

Images from each experimental process are provided throughout the section with relation to each process.

4.1 Equipment and Materials

The material components used for the construction of grout prisms, as well as their mix proportions, are per ASTM Standard C476 as listed previously in Table 01: Specified Mix. The components within each grout mixture were:

- Cement
- Water
- Pea gravel aggregate
- Washed sand

The equipment needed to conduct the mixing included:

- A wheelbarrow
- Standard steel drum mixer
- Gallon buckets for transporting materials

The equipment needed to conduct the slump testing for the 0.74:1.00 standard grout mixture included:

- A slump cone mold
- Agitating rods
- Slump testing level surface
- A measuring tape

The equipment needed to conduct the slump flow testing for the 1.00:1.00 self-consolidating grout mixture included:

- A slump cone mold
- Slump flow testing level surface
- A measuring tape
- Non-absorbent flat board (a double layered – flat two pieces of 1 inch plywood and varnished by students and used for slump flow testing)

The equipment needed to conduct the curing process included:

- 24 Concrete masonry unit (CMU) blocks
- Level surface located in a room with constant temperatures

The equipment needed to cut out the prisms and store them for final curing stages included:

- Water jet cutting saws
- A moisture-controlled room
- A submersion tank with access to water

The equipment needed for the capping and testing included:

- Gypsum cement
- Flat plates (glass and metal plates were used)
- Non-stick spray
- The Forney Testing Hydraulic Actuator (model # QC-50-106)

4.2 Experiment Location

The grout prisms were mixed and poured in the concrete yard of the Architectural Engineering department in the College of Architecture and Environmental Design. The compressive strength testing for the prisms were conducted at the California Polytechnic State University, San Luis Obispo in the Engineering West Building 21, Room 17.

4.3 Procedures

The following section provides procedures, with images, for mixing and testing grout prisms at 7 days, 28 days, and 42 days after casting.

4.3.1 Mix Process

Prior to mixing, calculations for the quantity of each part of the grout mixture were completed as outlined in section 2.0 Introduction. A standard steel mixing drum was used to combine the components calculated shown in Figure 02.

Components of the grout mixture were added to the drum in the following order: in order to control the water to cement ratio the dry components were added into the mixer first (cement, washed sands, and pea gravel aggregate); they were mixed thoroughly so that there was one consistent coloring throughout the mix. Then, water was added slowly in thirds so that the mixture did not form clumps – adding water in large amounts and too fast will create clumps of cement in the mixture which is not the consistency desired. The desired consistency for in the 0.74:1.00 grout mixture is smooth mashed potatoes. In the

1.00:1.00 grout mixture adding in the additional water creates a soup like consistency in the mixture.

Figure 02: Steel drum mixer used to mix all grout components together for the grout prisms.

4.3.2 Slump Test for 0.74:1.00 Standard Grout Mix

The American Standard Testing Method (ASTM) C143 outlines the standard test method for slump of sampling and testing of grout. After the correct consistencies were reached in the grout mixtures a slump test was performed for the 0.74:1.00 water-to-cement (W/C) ratio grout mixtures; shown in Figures 03 and 04. The slump test was conducted on a flat level surface – the concrete lab floor in the concrete yard in building 21 was used for this part of the experiment and shown in Figure 05. All equipment used to perform the slump test are shown in Figure 06. To conduct the slump test we followed the steps outlined below:

- Place feet on slump cone mold to make sure it does not move or shift when pouring the grout mix into the slump cone
- Pour grout mix into the slump cone – in three separate lifts, rodded in between each lift – be careful not to touch bottom of layer or prism when rodding
- Once the slump cone is filled, roll the edge of the rod over the lid to score off the top of the slump cone
- Lift the slump cone mold directly upwards – make sure to lift continuously in one motion within a second
- Measure the height of the resulting slump – from the top of the mold to the center of the peak of the slump

If the desired slump test result was not achieved, the mix design was altered and a new batch of grout must be made until a desired slump test result is achieved.

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Figure 03: Slump Test result of the first standard grout mix produced. Slump measured 8.25 inches.

Figure 04: Slump Test result of the second standard grout mix produced. Slump measured 8.00 inches.

Figure 05: The flat area where the slump cone tests were conducted.

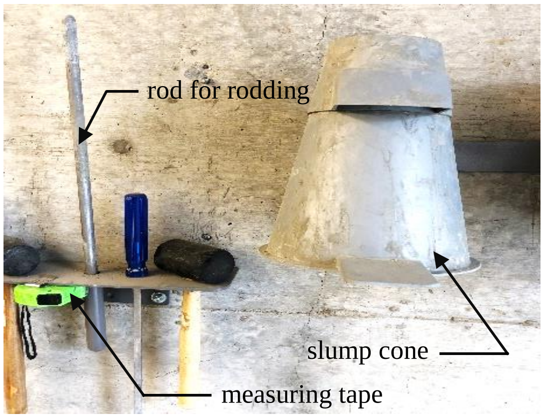

Figure 06: The slump cone, measuring tape, rod for rodding.

4.3.3 Slump Flow Test for 1.00:1.00 Self-Consolidating Grout Mix

The American Standard Testing Method (ASTM) C1611 which outlines the standard testing method for slump flow of self-consolidating grout. For the 1.00:1.00 W/C ratio grout mixture, a slump flow test was performed once all the water had been added to the mix shown in Figure 07. The slump flow test required a flat surface for the test to be performed on which is shown in Figure 08. It also required a board that is impermeable to water – a waterproofed double-sided plywood surface, glued together, sanded down, and varnished with a waterproofing seal, was used during the test and is shown in Figures 09. To conduct the slump flow test we followed the steps outlined below:

- Place feet on the slump cone mold to make sure it did not move or shift when pouring the grout mix into the slump cone
- Pour grout mix into the slump cone in ONE lift
- DO NOT ROD in between each lift

- Once the slump cone is filled, roll edge of the rod over the lid to score off the top of the slump cone
- Lift the slump cone mold directly upwards – make sure to lift continuously in one motion within a second
- Measure the diameters of the slump flow (smallest diameter and largest diameter) – average the two diameters to find the slump flow diameter

Figure 07: Slump Flow test results for the grout mixture with 1.00:1.00 water to cement ratio. The slump measured was 34.38 inches. No evidence of bleeding or segregation.

Figure 08: Area where the slump flow test was performed.

Figure 09: The set-up of the slump flow test before it was performed.

4.3.4 Curing Process

After slump tests and slump flow tests, the grout mixtures were poured into grout prism molds. Concrete masonry unit (CMU) blocks were chosen as a mold for this experiment (see Section 3.3). Pouring of the 0.74:1.00 grout mixtures into the molds took place in three separate layers, pausing to rod each layer with a specified number of rodding strokes to distribute the aggregates uniformly within the grout mix before moving onto the next layer.

Careful strokes as to not hit the bottom of the prisms were exercised. The 1.00:1.00 grout mixture was poured in all at once and there was no rodding of the layer.

Upon completion, the specimens were stored in the High Bay Lab with proper clean up to follow Shown in Figure 10 and 11. The curing room had constant temperature and the prisms were covered for 48 hours.

Figure 10: The CMU block molds before grout mixes are added. Area where the prisms were cured for the first 48 hours.

Figure 11: CMU blocks were the forms used to mold and cure prisms.

4.3.5 Cutting Prisms and Final Curing Stages

After curing for 48 hours, the prisms were cut using a water saw blade to prisms the size of three inches by three inches, and eight inches in height; with 0.25 inches of tolerance. Two separate wet saws were used to cut – one wet saw was able to make one direct cut straight through the concrete masonry unit (CMU) mold, the other wet saw required the block to be rotated and cut twice because the radius of the blade was not deep enough to make one single cut straight through. A fully cut prism is shown in Figure 12. Once cut out of the CMU molds, each of the specimens were submerged fully in a tank in a moisture-controlled room until testing shown in Figures 13 and 14. There are different options for curing grout prisms – submersion, onsite curing, and humidifier curing room. Submersion curing was chosen because it was the option most readily available at the time.

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Figure 12: A cut 1.00:1.00 grout mix prism from the concrete masonry unit (CMU) block mold. Water saws were used to cut the final prism out of the molds.

Figure 13: Prisms on the left were the 1.00:1.00 W/C ratio grout mixture and the ones on the right were 0.74:1.00 grout mixtures.

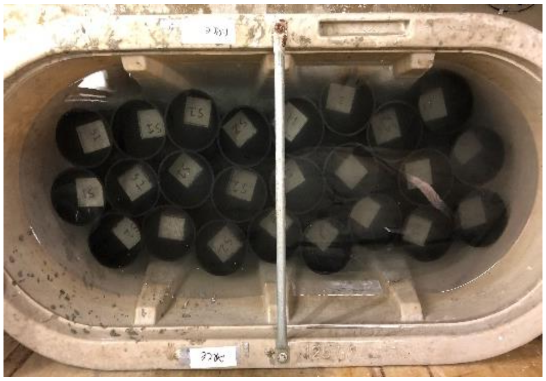

Figure 14: Prisms fully submerged with water in submersion tank.

4.3.6 Capping and Testing of Prisms

After curing for 7 days, 28 days, and 42 days the grout prisms were tested. There were four 0.74:1.00 standard grout mixture prisms and four 1.00:1.00 self-consolidating grout mixture prisms tested at each different testing day.

The capping of all bearing surfaces was achieved by gypsum cement. See American Standard Testing Method (ASTM) C140 for capping material requirements and other options for materials to be used in place of gypsum cement. The gypsum cement was mixed with a conservative amount of water until the consistency was similar to a glue like paste. In order to prevent air bubbles within the paste, the paste was pressed and folded into itself.

A glass plane and metal plate were used as flat surfaces to hold the gypsum cement mixture; all contact surfaces of both were covered in nonstick spray in order to prevent the gypsum cement mixture from sticking to the glass and metal plates during capping. A generous amount of the gypsum cement mixture was placed onto the glass plate, then the first prism was placed on top of the gypsum cement mixture. Another generous amount of the gypsum mixture was placed onto the top of the prism. Finally, the metal plate was added to the top of the gypsum mixture. An important note to make during the capping process is that all the components need to be level before the gypsum cement mixture starts to set. The mixture needed approximately 20 minutes to dry and set completely. Once set, the metal and glass plates were removed from the gypsum cement mixture. Once removed, the prisms were placed into the testing machine.

When testing the prisms, the centroid of the prism must be aligned vertically with the center of the hydraulic compressive head of the machine. The use of metal blocks decreased the distance between the head of the machine to the top of the prism. The load was applied at a consistent gradual rate. Once the loading started to decrease, the load was removed and the rate of loading and final load of the test was recorded. This final loading was used to calculate the compressive strength of the prism.

5.0 RESULTS

This section provides the results of the grout prism testing. There were three testing days – 7 day, 28 days, and 42 days. Please refer to section 4.3.6 capping and testing of prisms for the procedure for grout prism testing. Tables 04 – 07 outline the results of the testing performed.

5.1 7 Day Testing Results

Testing took place on Monday, November 5th, 2018.

Table 04: 7 Day Test Results

Grout Mixture 0.74:1.00 W/C Ratio	Width (in)	Length (in)	Height (in)	Final Loading (psi)	**Compressive Strength (kips)**
Prism 1	3.25	3.50	7.50	2,443.10	27.79
Prism 2	3.00	3.15	7.50	3,415.90	32.28
Prism 3	3.15	3.25	7.50	2,609.00	26.71
Prism 4	3.00	3.25	7.50	2,954.52	28.81
Average					**28.90**
Grout Mixture 1.00:1.00 W/C Ratio	Width (in)	Length (in)	Height (in)	Final Loading (psi)	**Compressive Strength (kips)**
Prism 1	3.25	3.00	7.50	1,795.90	17.51
Prism 2	3.25	3.25	7.50	1,679.00	17.73
Prism 3	3.00	3.15	7.50	1,722.80	16.28
Prism 4	3.00	3.25	7.50	1,852.10	18.06
Average					**17.40**

5.2 28 Day Testing Results

Testing took place on Sunday, November 25th, 2018.

Table 05: 28 Day Test Results

Grout Mixture 0.74:1.00 W/C Ratio	Width (in)	Length (in)	Height (in)	Final Loading (psi)	**Compressive Strength (kips)**
Prism 1	3.25	3.25	7.25	3,173.50	33.52
Prism 2	3.25	3.25	7.25	3,777.50	39.90
Prism 3	3.25	3.25	7.25	4,037.90	42.65
Prism 4	3.25	3.25	7.25	4,043.60	42.71
Average					**39.70**
Grout Mixture 1.00:1.00 W/C Ratio	Width (in)	Length (in)	Height (in)	Final Loading (psi)	**Compressive Strength (kips)**
Prism 1	3.25	3.25	7.25	1,752.45	18.51
Prism 2	3.25	3.25	7.25	1,388.30	14.66
Prism 3	3.25	3.25	7.25	1,597.30	16.87
Prism 4	3.25	3.25	7.25	1,694.30	17.90
Average					**16.99**

5.3 42 Day Testing Results

Testing took place on Friday, December 14th, 2018.

Table 06: 42 Day Test Results

Grout Mixture 0.74:1.00 W/C Ratio	Width (in)	Length (in)	Height (in)	Final Loading (psi)	**Compressive Strength (kips)**
Prism 1	3.25	3.00	8.00	4,206.00	41.01
Prism 2	3.25	3.25	8.00	5,102.00	53.89
Prism 3	3.25	3.15	8.00	3,948.60	40.42
Prism 4	3.25	3.25	8.00	6,001.95	63.40
Average					**49.68**
Grout Mixture 1.00:1.00 W/C Ratio	Width (in)	Length (in)	Height (in)	Final Loading (psi)	**Compressive Strength (kips)**
Prism 1	3.25	3.25	8.00	2,901.64	30.65
Prism 2	3.25	3.25	8.00	3,102.96	32.78
Prism 3	3.00	3.25	8.00	3,000.67	29.26
Prism 4	3.00	3.25	8.00	2,998.76	29.24
Average					**30.48**

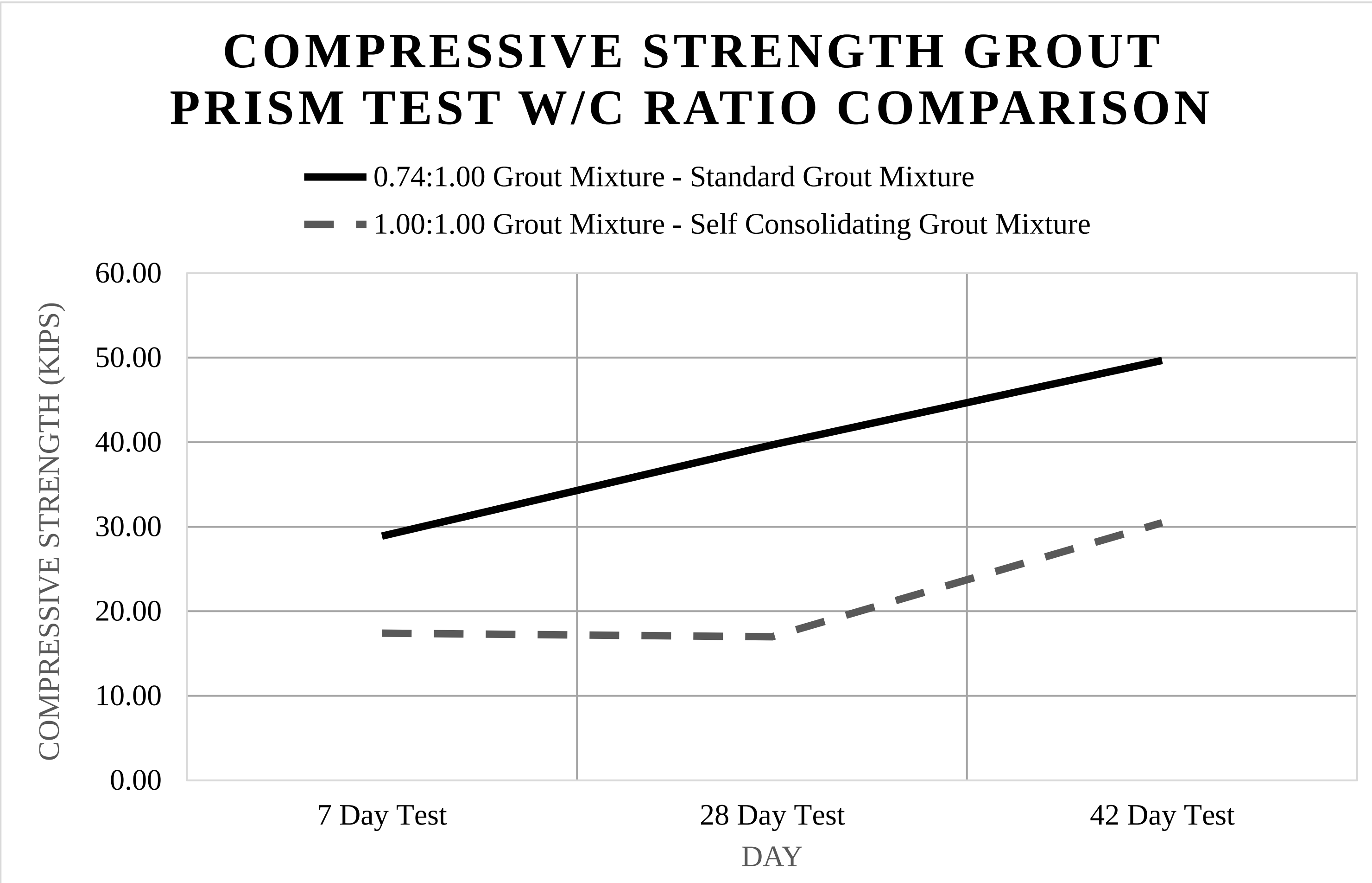

Table 07: Compressive Strength Comparisons for Grout Prism Tests

	0.74:1.00 Grout Mixture – Standard Grout Mixture	**1.00:1.00 Grout Mixture – Self-Consolidating Grout Mixture**	**Percent Decrease in Strength of 1.00:1.00 Grout Mixture**
7 Day Test	28.90 kip	17.40 kip	39.79 %
28 Day Test	39.70 kip	16.99 kip	57.20 %
42 Day Test	49.68 kip	30.48 kip	38.65 %

5.4 Strength of Grout Mixtures Discussion

The follow discussion is based on the results of the compressive strength grout prism testing done in order to compare a standard grout mixture to a self-consolidating grout mixture. The 1.00:1.00 grout mixture had decrease in strength consistently at each testing point shown in Table 07. It is important to note the percent decrease in strength of the 1.00:1.00 grout mixture at each stage of

testing. The results were what we expected – the two mixtures start with a small gap in strength at 7 days, at the 28 day test this gap in strength is increased, and then at 42 days the gap in strength is reduced.

5.5 Comparison of Consolidation Patterns and Aggregate Matrix

The following pictures represent the aggregate matrices within the grout prisms. Table 08 represents the approximate amount of aggregate per inch in each grout mixture.

Figure 04: Aggregate matrix from 0.74:1.00 grout mixture (standard grout mixture).

Figure 05: Aggregate matrix from 1.00:1.00 grout mixture (self-consolidating grout mixture).

Table 08: Aggregate Matrix: Aggregate per Inch

	0.74:1.00 Grout Mixture – Standard Grout Mixture	**1.00:1.00 Grout Mixture – Self-Consolidating Grout Mixture**	**Percent Increase in Aggregate per Inch of 1.00:1.00 Grout Mixture**
Approximate Aggregate per Inch	7	18	61 %

5.6 Consolidation and Aggregate Matrix Discussion

The follow discussion is based on the results of the comparison of aggregate per inch within a grout prism that was done in order to compare a standard grout mixture to a self-consolidating grout mixture's aggregate matrix. This is helpful in determining the consolidation of a grout mixture. When an increase in water content is added to the grout mixture, an increase in consolidation occurs. There is approximately a 61% increase in aggregate per inch within the 1.00:1.00 grout mixture shown in Table 08. While adding more water to the grout mixture provides a more consolidated mixture, it in turn will have a decrease in strength as seen in Table 07.

7.0 CITATIONS

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