Constructed Facilities Laboratory

Department of Civil, Construction, and Environmental Engineering

Summary Report

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Comparison of Cylinder and Cube Strength for Typical Grouts

Authors:

Arjun Jayaprakash, Christopher Price, Andy Jiang, Mohammad Pour-Ghaz, James Nau and Mervyn Kowalsky

Prepared for:

Alaska Department of Transportation

Constructed Facilities Laboratory

2414 Campus Shore Drive

North Carolina State University

Raleigh, NC 27695-7533

Tel: (919) 513-1733

Fax: (919) 513-1765

Email: cfl@ncsu.edu

Web Site: www.cfl.ncsu.edu

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Introduction:

A series of compressive strength tests was performed on four different high strength cementitious grouts. Tests were performed on both 2”x 2” cubic samples and 4”x 8” cylindrical samples. The objectives of the tests were to investigate the following:

1. Variability of strengths for cubic samples.
2. Differences between cylinder strength and cube strength of cementitious grouts.
3. Compare compressive strengths of typical high strength grouts.

The size and testing protocol for testing cylindrical samples followed ASTM C39 [1]. Cubic samples were based on ASTM C109 [2], although the standard was not strictly followed. ASTM C109 [2] specifies the cubes to be cured in lime water after 24 hours whereas the specimens tested here were sealed cured. The standard does not specify the use of polymer pad caps over the loading faces. However, such caps were used to test these samples. Samples were tested on their 3rd, 7th, 28th and 90th day after casting. All of the commercial grout materials that were tested specify compressive strengths of cube specimens in their respective data sheets.

The following section discusses the procedure that was followed and the results are discussed in the subsequent section. Results are then summarized in the section titled ‘Summary’. All test data has been included in the Appendix.

Procedure:

<u>Materials used</u>

1. Concrete mixer – Multiquip Polyethylene-Drum Concrete Mixer (Model MC94PH8)
2. Grouts used:
   a. Dayton Superior Sure-Grip High Performance (Dayton HP)
   b. Dayton Superior Advantage 1107 (Dayton 1107)
   c. Sakrete Non-Shrink Construction Grout (Sakrete)
   d. BASF MasterFlow 928 (BASF)
3. Potable water at room temperature
4. 2” x 2” aluminum cubic molds – These were fabricated in-house (Figure 1).
5. Disposable plastic cubic liners – Gilson Company, Inc. HMA-140 Extra liners (Figure 1)
6. Polymer pad caps – Gilson Company, Inc. HMA-141 Pad Caps (2”)
7. 4”x 8” cylindrical molds – Commercially available grey plastic test cylinder molds
8. Vibrating table – Buffalo vibrator number 200
9. Testing machine – Forney compressive strength testing machine

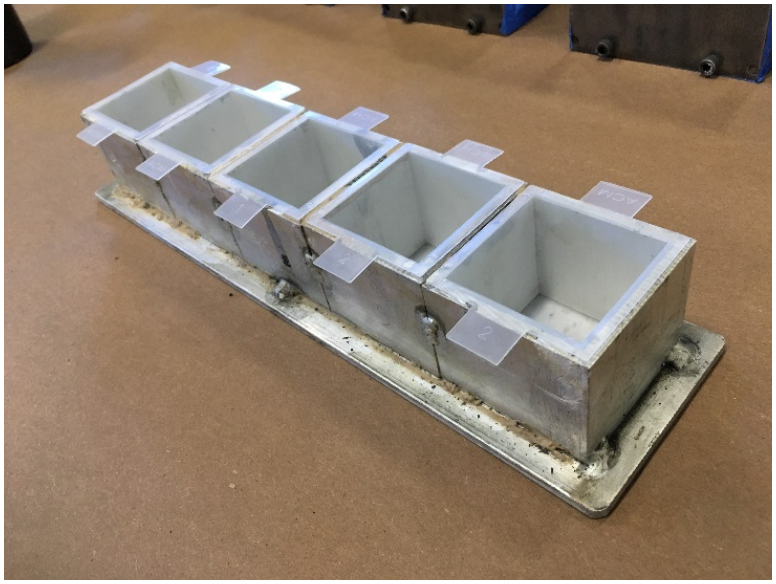

Figure 1: A photograph of 2”x 2” Cubic molds used for the preparing test samples.

Preparation

The inside of the mixer was sprayed with water to rinse out loose debris, then wiped with a wet towel. The materials to be mixed were then measured. Grout material bag weights and required water content vary for different manufacturers. Bag weights of all the tested grout materials and the corresponding water content used are given in Table 1. Disposable plastic cubic liners were inserted into fabricated aluminum molds as shown in Figure 1. The purpose of the outer mold is only to avoid deformation of the disposable plastic liners. Once the grout set, these plastic liners along with the hardened grout slid out of the aluminum molds easily. The plastic liners prevented bleeding and leakage of grout paste from the molds. This was important because leakage and bleeding in small samples result in loss of a high percentage of water compared to the total volume of sample. In addition, the plastic liners prevented drying during curing and also eliminated the need for form release agent that may potentially affect hydration. Conventional 4”x 8” cylindrical molds were also prepared according to ASTM C39 [1].

Grout	Bag Weight (lbs.)	Water added per bag (lbs.)	Consistency label*
Dayton HP	50	6.6	Flowable
Dayton 1107	50	8.4	Flowable
Sakrete	50	9.3	Flowable
BASF	55	8.5	-

* Label specified by manufacturer corresponding to the amount of water.

Table 1: Grouts used, bag weights, and the amount of water added in each mixture.

Mixing

About half of the total amount of water was first poured into the mixer. All of the grout material was then transferred into the mixer. Some hand mixing was done using a hand shovel to spread out the grout and water before turning on the mixer. Once the mixer paddle started rotating, the remaining water was added in parts, in no particular quantities, within the next 2 to 3 minutes. The mixer was stopped occasionally to check for dry cement adhering to the drum walls. Any dry cement was scraped off of the walls to facilitate better mixing. This process was continued for 10 to 15 minutes. The mixing time varied depending on the grout material brand, volume of grout material, and the ambient temperature. Mixing was concluded once the mixture was deemed flowable by visual inspection. Figure 2 contains photographs of the mixer and the mixture.

Placement

After mixing, the grout was taken out of the mixer in small amounts when required, using a 5-gallon bucket. The remaining grout was left inside the mixer which was turned back on to retain workability. The molds were placed on a small vibrating table. Grout was then scooped in a measuring cup and poured into the prepared molds. Pulses of vibration were provided as needed to fill each mold (Figure 3). Each sample was carefully finished to obtain a smooth surface. The 4” x 8” cylinder molds were also filled according to ASTM C39 [1].

Figure 2: Photographs of the mixer used to prepare test samples.

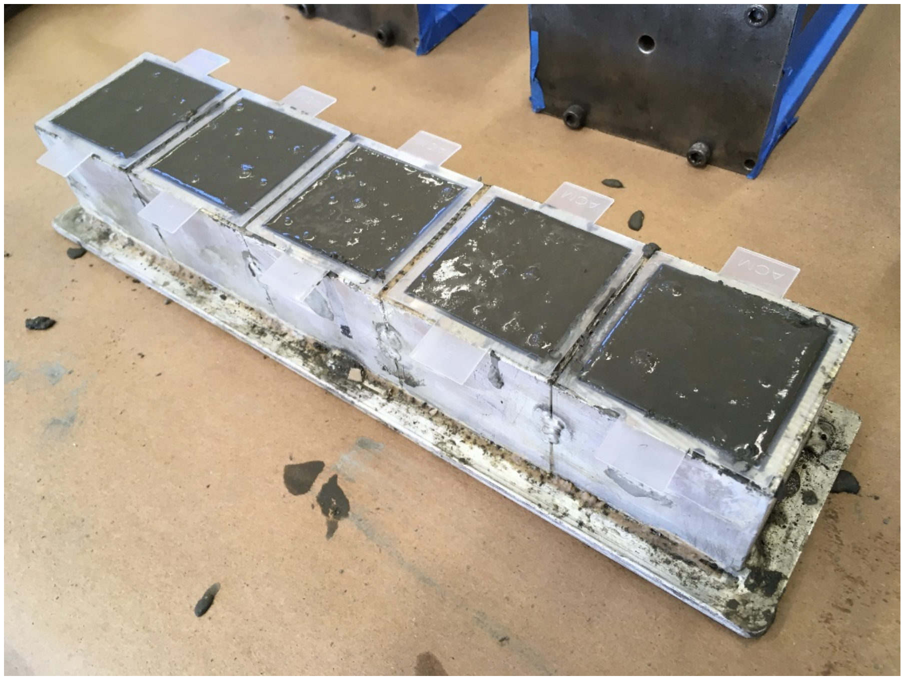

Figure 3: Grout filled cubic molds.

Figure 4: Photograph showing how samples were cured for the first 24 hours.

Curing

After placement, the cubic molds were covered using a layer of transparent plastic sheet below water saturated cloth and a second layer of plastic sheet on top to prevent any loss of moisture as shown in Figure 4. The samples were then stored for 24 hours. After 24 hours, the transparent plastic sheets and the cloth were removed and the hardened grout cubes with the surrounding plastic molds were taken out of the aluminum molds (Figure 5a). These samples were then stored (samples remain within the plastic liners) in two layers of heat-sealed transparent plastic bags until the day of testing (Figure 5b). 4” x 8” cylinders were also stored inside the molds until testing. The caps of the cylindrical molds were sealed tight to the body with tape to avoid evaporation.

Figure 5: (a) Hardened grout after 24 hours and (b) Sealed samples.

Testing

Testing was carried out 3, 7, 28 and 90 days after casting. 4” x 8” cylinders were tested according to ASTM C39 [1]. On the day of testing, the cubic samples were first taken out of the sealed transparent plastic bags and then removed from the disposable plastic liners. This was done by drilling a small hole on the bottom face of the mold through which compressed air was passed. The plastic liners were discarded after the samples slid out. The cubic samples would typically have 1 uneven and 5 even sides. Two opposite sides that were even were selected to apply the compressive load. Two polymer pad caps were then placed on both of these sides to allow a uniform distribution of pressure (Figure 6). Figure 7 show the specimens being tested.

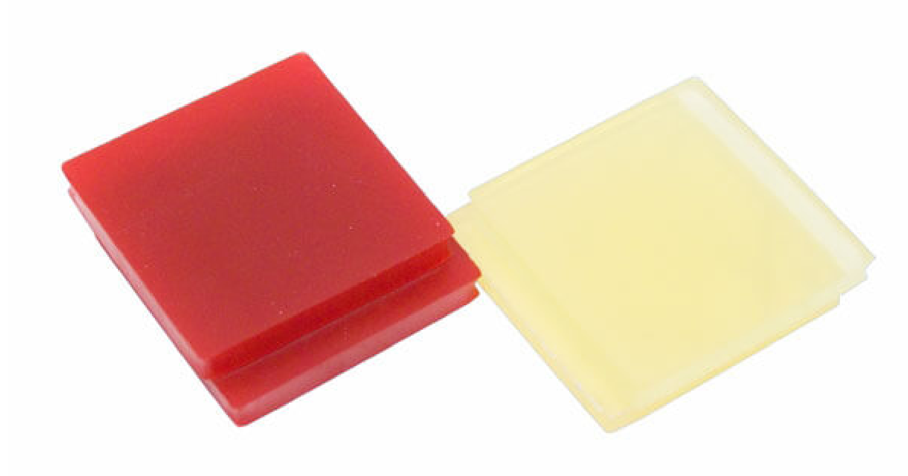

Figure 6: Pad caps used for cube compressive strength tests (Courtesy: Gilson Company Inc.).

Figure 7: Cylinder and cube specimen being tested.

Grout	Average Strengths (ksi)							
	3-day		7-day		28-day		90-day	
	Cube	Cylinder	Cube	Cylinder	Cube	Cylinder	Cube	Cylinder
Dayton HP	10.21	8.10	10.41	8.91	10.41	9.86	-	-
Dayton 1107	7.19	7.16	8.93	8.04	9.91	9.05	10.44	9.60
Sakrete	6.47	5.60	7.15	7.42	8.60	8.43	10.76	9.44
BASF Masterflow	8.44	7.84	10.20	8.80	11.47	10.60	12.27	11.04

Table 2: Summary of the results – average compressive strengths.

Grout	Coefficients of Variation							
	3-day		7-day		28-day		90-day	
	Cube	Cylinder	Cube	Cylinder	Cube	Cylinder	Cube	Cylinder
Dayton HP	0.05	0.01	0.03	0.03	0.08	0.03	-	-
Dayton 1107	0.02	0.04	0.04	0.04	0.05	0.02	0.10	0.05
Sakrete	0.11	0.02	0.12	0.02	0.09	0.05	0.08	0.04
BASF Masterflow	0.05	0.03	0.03	0.00	0.07	0.07	0.04	0.07

Table 3: Summary of the results – coefficients of variation for average compressive strengths.

Results and Discussion:

The average strengths of cube and cylinder samples at different ages are provided in Table 2. Note that the 90-day strength for Dayton HP could not be tested. The coefficients of variation of each value in Table 2 are provided in Table 3. Overall, cylinder strength specimens showed less variation compared to cube strength specimens. This was expected as cylinders, being large samples, are more homogenous across the length-scale as compared to the smaller cubes. The average coefficient of variations for cubes and cylinders were 0.06 and 0.03, respectively. Figure 8 provides a graphical representation of the data. Note that the cubes for Dayton HP show almost equal strength at all ages, a result which is not consistent with the cylinders from the same batch. A likely reason for this is improper curing. Cubes of Dayton HP grout were not sealed after demolding. Drying ensued preventing further hydration. This halted strength gain. The authors would like to emphasize the importance of curing for strength test samples, especially for cubic specimens since they can lose significant amount of moisture rapidly. Data from other grouts, which were cured without moisture loss, show an increase in strength with age. The error bars indicate one standard deviation above and below the mean of the sample data. Compressive strengths of cubes are higher than those of cylinders, on average. This conforms to expectations

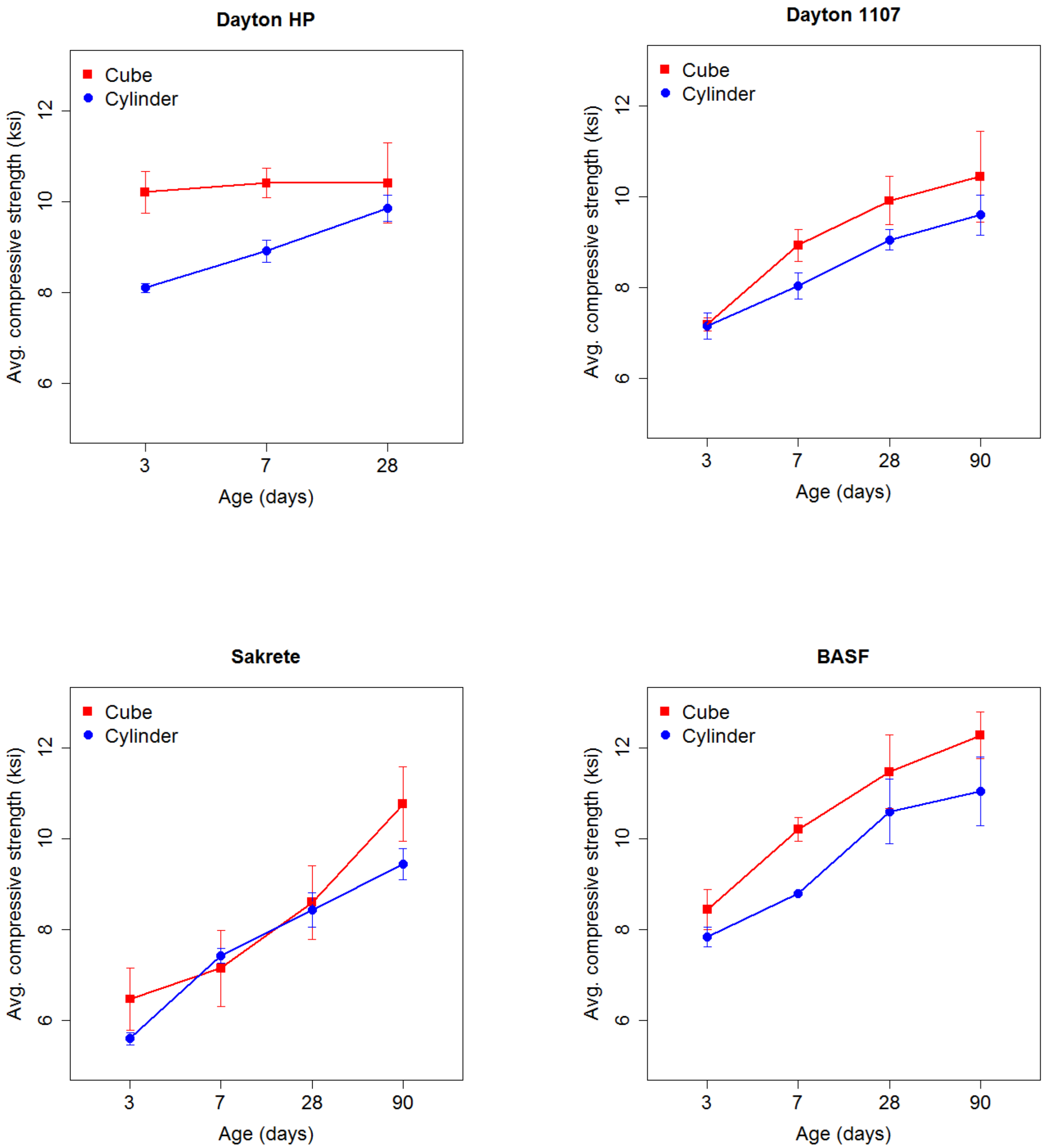

Figure 8: Comparison of cube strength and cylinder strength for all the tested grouts.

as specimens with higher aspect ratios show lower strengths. Cube and cylinder samples had an aspect ratio of 1 and 2 respectively. Both classifications of strength show the same pattern of increase with age, which indicates that measuring strength of grout cubes can be a valid alternative to measuring strength of grout cylinders, if all steps of testing are performed properly. Figure 9 shows a comparison of measured strengths between the tested grouts. BASF and Dayton HP showed high strengths very early and kept increasing up to 90 and 28 days respectively. Sakrete and Dayton 1107 had comparatively lower early age strength and a lower 90-day strength compared to BASF and Dayton HP.

All the average cylinder strengths are compared to their corresponding average cube strengths in Figure 10. Any point on the red line are points of equal strength. Cube strengths are almost always greater than cylinder strengths as can be observed from the fact that almost all points lie above the red line. The data is also suggestive of a linear correlation between cube and cylinder strengths. A linear fit to the data is shown in Figure 10.

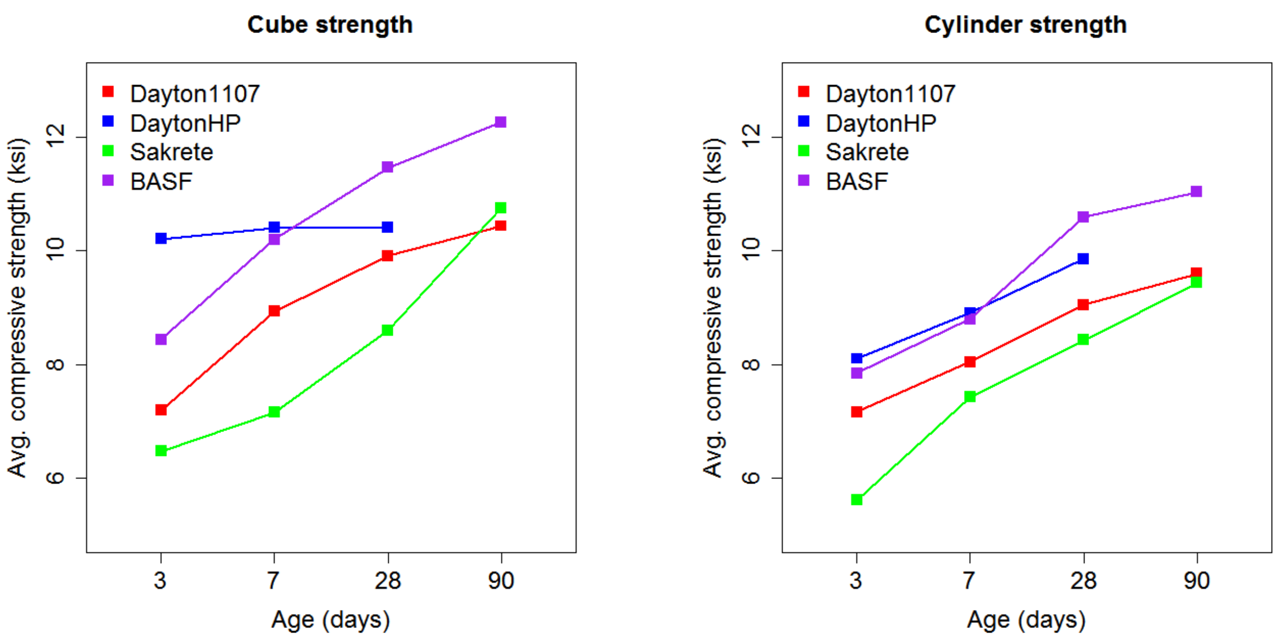

Figure 9: Comparison of compressive strengths of all tested grouts (Cube strength and Cylinder strength).

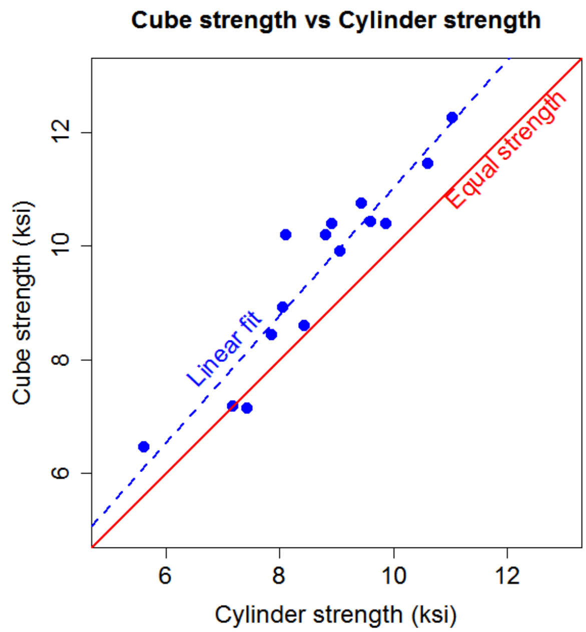

Figure 10: All average cube strengths versus average cylinder strengths.

Summary:

The objective of the tests performed was to find the compressive strengths of cube and cylinder specimens of four commercially available cementitious grouts, and to examine the variability and relationship between the two strength classifications (cube vs cylinder). Cylinder strength tests were performed according to ASTM C39 [1] while the cube strength tests were performed based on ASTM C109 [2] with some modifications. The tests showed that on average, cube strengths were higher and had a higher variability compared to cylinder strengths. However, the variability for both classifications is low and hence both approaches can be used as reliable measures of compressive strengths of grout.

Referenced Documents:

<u>ASTM Standards:</u>

1. C39/39M Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.
2. C109/109M Standard Test Method for Compressive Strength of Hydraulic Cement Mortars.

Appendix:

Table A1. Results from all test samples

Manufacturer	Geometry	Age (days)	Compressive Strength (ksi)
DaytonHP	Cylinder	3	8.20
DaytonHP	Cylinder	3	8.00
DaytonHP	Cylinder	3	8.08
DaytonHP	Cubes	3	9.77
DaytonHP	Cubes	3	10.69
DaytonHP	Cubes	3	10.16
DaytonHP	Cylinder	7	9.17
DaytonHP	Cylinder	7	8.89
DaytonHP	Cylinder	7	8.67
DaytonHP	Cubes	7	10.74
DaytonHP	Cubes	7	10.15
DaytonHP	Cubes	7	10.67
DaytonHP	Cubes	7	10.50
DaytonHP	Cubes	7	9.98
DaytonHP	Cylinder	28	10.07
DaytonHP	Cylinder	28	9.53
DaytonHP	Cylinder	28	9.98
DaytonHP	Cubes	28	10.96
DaytonHP	Cubes	28	9.89
DaytonHP	Cubes	28	9.78
DaytonHP	Cubes	28	9.73
DaytonHP	Cubes	28	11.69
Sakrete	Cylinder	3	5.45
Sakrete	Cylinder	3	5.69
Sakrete	Cylinder	3	5.65
Sakrete	Cubes	3	7.27
Sakrete	Cubes	3	6.63
Sakrete	Cubes	3	6.39
Sakrete	Cubes	3	6.67
Sakrete	Cubes	3	5.38
Sakrete	Cylinder	7	7.27
Sakrete	Cylinder	7	7.41
Sakrete	Cylinder	7	7.58
Sakrete	Cubes	7	7.57
Sakrete	Cubes	7	6.09
Sakrete	Cubes	7	8.16
Sakrete	Cubes	7	6.50

Sakrete	Cubes	7	7.45
Sakrete	Cylinder	28	8.11
Sakrete	Cylinder	28	8.85
Sakrete	Cylinder	28	8.32
Sakrete	Cubes	28	7.34
Sakrete	Cubes	28	8.93
Sakrete	Cubes	28	9.05
Sakrete	Cubes	28	8.27
Sakrete	Cubes	28	9.40
Sakrete	Cylinder	90	9.76
Sakrete	Cylinder	90	9.49
Sakrete	Cylinder	90	9.08
Sakrete	Cubes	90	9.61
Sakrete	Cubes	90	11.25
Sakrete	Cubes	90	10.43
Sakrete	Cubes	90	10.74
Sakrete	Cubes	90	11.77
Dayton1107	Cylinder	3	7.29
Dayton1107	Cylinder	3	6.83
Dayton1107	Cylinder	3	7.36
Dayton1107	Cubes	3	7.03
Dayton1107	Cubes	3	7.27
Dayton1107	Cubes	3	7.22
Dayton1107	Cubes	3	7.05
Dayton1107	Cubes	3	7.37
Dayton1107	Cylinder	7	8.15
Dayton1107	Cylinder	7	7.71
Dayton1107	Cylinder	7	8.26
Dayton1107	Cubes	7	8.41
Dayton1107	Cubes	7	9.10
Dayton1107	Cubes	7	8.75
Dayton1107	Cubes	7	9.24
Dayton1107	Cubes	7	9.17
Dayton1107	Cylinder	28	8.82
Dayton1107	Cylinder	28	9.07
Dayton1107	Cylinder	28	9.25
Dayton1107	Cubes	28	10.13
Dayton1107	Cubes	28	9.63
Dayton1107	Cubes	28	10.55
Dayton1107	Cubes	28	9.16
Dayton1107	Cubes	28	10.06

Dayton1107	Cylinder	90	9.29
Dayton1107	Cylinder	90	10.11
Dayton1107	Cylinder	90	9.41
Dayton1107	Cubes	90	8.76
Dayton1107	Cubes	90	10.94
Dayton1107	Cubes	90	11.15
Dayton1107	Cubes	90	11.09
Dayton1107	Cubes	90	10.28
BASF	Cylinder	3	8.05
BASF	Cylinder	3	7.63
BASF	Cylinder	3	7.84
BASF	Cubes	3	8.74
BASF	Cubes	3	8.43
BASF	Cubes	3	8.57
BASF	Cubes	3	7.68
BASF	Cubes	3	8.78
BASF	Cylinder	7	8.78
BASF	Cylinder	7	8.82
BASF	Cylinder	7	8.80
BASF	Cubes	7	9.97
BASF	Cubes	7	10.60
BASF	Cubes	7	9.99
BASF	Cubes	7	10.17
BASF	Cubes	7	10.29
BASF	Cylinder	28	9.96
BASF	Cylinder	28	11.36
BASF	Cylinder	28	10.49
BASF	Cubes	28	12.29
BASF	Cubes	28	10.51
BASF	Cubes	28	11.97
BASF	Cubes	28	11.11
BASF	Cylinder	90	10.41
BASF	Cylinder	90	10.84
BASF	Cylinder	90	11.88
BASF	Cubes	90	12.60
BASF	Cubes	90	11.49
BASF	Cubes	90	12.55
BASF	Cubes	90	12.01
BASF	Cubes	90	12.69