STRENGTH OF CONCRETE MASONRY UNITS WITH PLASTIC BOTTLE CORES

by

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Abstract

Concrete masonry units are a common method of construction in the world. Since the masonry units can be constructed with ease. Fifty billion water bottles are consumed every year. Lack of waste management and recycling in third world countries has come to the attention of many organizations. The use of plastic bottles in construction materials has been around for the past twenty years, but with little focus on using full plastic bottles in the materials. The Engineers Without Borders student group on the campus at Kansas State University have found a way to utilize the full 500-mL plastic bottle in the creation of concrete walls. The bottles laid horizontally with concrete on both sides and as mortar between the bottles was used. These bottles create large voids in the wall decreasing the compressive strength of the wall. This thesis presents the results of a study conducted to determine the compressive strength of concrete masonry units with plastic bottle cores. The plastic bottles were used to create the center voids in the masonry units. Concrete was placed around the bottles to encase them in the masonry units. The study utilized 500-mL plastic bottles from five different water companies placed inside masonry units of 7.87-inch wide by 8.26-inch high by 15.75-inch long (200-mm wide by 210-mm high by 400-mm long) in size and analyzed the resultant compressive strength. The testing for compressive strength was determined according to the ASTM C140 standard. Results from this study were deemed reasonable due to the testing of concrete cylinders as a control compressive strength. Determination of the compressive strength of the concrete masonry units allows for further study to continue in concrete masonry units with plastic bottle cores to determine if they are viable in third world countries.

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Acknowledgements

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Dedication

I wish to dedicate this research to my loving parents Michael and Deborah Wonderlich.

Chapter 1 - Introduction

Concrete masonry units are one type of building construction that can be used for building residential and commercial buildings. These units are available in various nominal unit shapes and sizes; one of the most common sizes is a nominal 8-inch wide by 8-inch high by 16-inch long (203.2-mm wide by 203.2-mm high by 406.4-mm long) block which has specified dimensions of 7.625-inch wide by 7.625-inch high by 15.625-inch long (193.7-mm wide by 193.7-mm high by 396.9-mm long). Actual dimensions are allowed a variation of ± 0.125-inch (3.2-mm). Concrete masonry units have two cores of 5.125-inch wide by 6.3125-inch long (130.2-mm wide by 160.3-mm long) in the middle of the block to help reduce the weight of the block and also allow for reinforcement and grout to be placed in the masonry wall. The face shell thicknesses of the concrete masonry units varies between 1-inch to 1.25-inch (25.4-mm to 31.8-mm).

Research conducted for this thesis utilizes plastic water bottles of five brands that are Dasani, Aquafina, Ozarka, Nestle, and Great Value, and place them as the cores for concrete masonry units. The units utilize a total of eight plastic bottles with each core of the masonry unit utilizing four plastic bottles. Concrete is placed around the plastic bottles in the plywood forms to create the concrete masonry unit.

Testing of new concrete masonry units is necessary to determine if the new design meets the ASTM standards. The use of ecological aggregate has been widely used in the last two decades of research (Stahl, 2002) with two of these studies being *Lightweight Concrete Masonry with Recycled Wood Aggregate* by Stahl et Al. and *Compressive Behavior of Concrete with Vitrified Soil Aggregate* by Palmquist et Al. Use of solid plastic bottles in concrete masonry units has not been regularly verified for the ASTM standards testing. Use of these bottles allows masonry units to be fabricated directly on a job site; reduced energy consumption by eliminating the recycling process; and reduction of pollution by not releasing the toxic fumes of melting the plastic bottles to be used as an aggregate in the concrete mix.

Concrete masonry units fabricated for this research are evaluated using ASTM standards to discern whether the units meet appropriate ASTM and MSJC standards for concrete masonry units. The ASTM standards for concrete masonry units require specific steps in the testing of the masonry units to regulate the testing and ensure results are uniform nationwide. While the MSJC standards provide specific requirements for concrete masonry units to be used in building design. The resulting conclusion determined if further research is required to justify the use of these concrete masonry units for the construction of residential and one-story commercial buildings. If viability is conformed, concrete masonry units with plastic bottle cores would be utilized primarily in third world countries that lack waste management services typical in more developed countries. This study focuses on construction in the Republic of Ecuador, and materials used in the concrete masonry blocks were determined to be readily available in that country by the members of the Engineers Without Borders student group on the campus of Kansas State University.

Chapter 2 - Background

The idea of utilizing plastic bottles in concrete building construction was originally conceived by Eco-Tec Environmental Solutions to help deal with global warming and to create less waste in the environment (Andreas Froese, 2014). Eco-Tec began using the bottles as a solution to the problem of garbage disposal that was asked by Andreas Froese with an innovative solution, Eco-Tec's primary activities include advising and training in green building, eco-design, composting, and vermiculture (Andreas Froese, 2014). Figure 2.1 shows the system that was configured by Eco-Tec.

Figure 2.1 Eco-Tec Plastic Bottle Wall System, reproduced from Andreas Froese

Kansas State University's Chapter of Engineers Without Borders (EWB) brought this idea to the Kansas State University campus. When EWB traveled to Ecuador they found an urgent need to reduce waste production throughout that country. Therefore, when EWB assisted with construction of residential buildings or one-story commercial structures in Ecuador, plastic bottles were placed horizontally and concrete was placed around the bottles, as shown in Figure 2.2.

Figure 2.2 EWB Concrete Wall with Plastic Bottles, approval from Richard Kim

The inclusion of plastic bottles within concrete walls causes the walls to have mostly voided regions. Therefore, the idea of utilizing plastic bottles within a masonry wall was conceived. Masonry walls are stronger than concrete walls in compression because voids are present in the wall thickness which means that there is more area for the compressive force to be applied to. The concept was that the 500-mL plastic bottles will be used as the formwork to create the voids of the masonry blocks of 7.625-inch wide by 7.625-inch high by 7.625-in long (193.7-mm wide by 193.7-mm high by 396.9-mm long) with the face shell thickness of 1.25-inch (31.8-mm). The blocks are fabricated in the laboratory, utilizing four plastic bottles for each core of the masonry unit. After the masonry blocks completed the required 28 days of curing, they were available for placement to form walls of residential or one-story commercial buildings. However, concrete masonry units must first be evaluated using ASTM standards for masonry blocks.

This thesis investigates if concrete masonry units meet the ASTM standard of C140 *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units.* This research will encourage further development of concrete masonry units with plastic bottle cores. The conducted research studied compressive strength of concrete masonry units for a specific concrete mix design.

Chapter 3 - Literature Review

In order to fully understand the behavior of concrete masonry units with plastic bottle cores, other concrete masonry units and their behaviors must be investigated. Even though the materials may differ, many of the mechanisms and behaviors are very similar. These validate data obtained by the testing of the concrete masonry units with plastic bottle cores. The concrete block masonry mix design that is used for this study was based on the study by Babrak Amiri and others called *Lightweight High-Performance Concrete Masonry-Block Mix Design* in 1994. This study looked at 41 different concrete mix designs and evaluated the compressive strength with different aggregates. A study conducted by Sammu Rahgu De Silva Chandrakeerthy titled *Compressive Strength Test for Low-Strength Cement Blocks* follows the steps used for testing low-strength concrete masonry units. This study helped guide the test plan used for the concrete masonry units with plastic bottle cores. The last study I reviewed before beginning the tests presented in this paper was the study conducted by Douglas C. Stahl and others titled *Lightweight Concrete Masonry with Recycled Wood Aggregate.* This study indicated what special requirements would need to be addressed when introducing an aggregate or item into a concrete masonry unit and how the concrete mix and plastic bottles would react.

Concrete Block Masonry Mix Design

Compressive characteristics of masonry blocks have been analyzed for quite some time. In the early to mid-1990s Babrak Amiri, Gary L. Krause, and Maher K. Tadros completed a study called *Lightweight High-Performance Concrete Masonry-Block Mix Design* (1994) in which they analyzed 41 different concrete mix designs to obtain a higher compressive strength while producing a lighter concrete block. The study attempts to determine the most economical mix design to obtain a lightweight high-performance concrete masonry block able to be produced in a production facility.

Amiri's study was conducted in two phases, with the first phase being a purely laboratory study in which the concrete mix designs were determined for the phase 2 of the study. The first phase included the creation of test cylinders of 4-inch diameter by 4.6-inch high (101.6-mm diameter by 116.8-mm high) which were tested for compressive strength. Mix designs most applicable to concrete masonry blocks with plastic bottle cores are presented in Table 3.1.

Table 3.1 Concrete Mix Designs (Percentages by Weight) for Amiri Study

Mix No.	Aggregate				Cement	Fly Ash	Water	Strength 24 hrs.	Strength 28 days
	3/8 – 1/4	1/4 - 1/8	1/8 - 0	Sand					
3	88				7	2	3	973	1997
7	16	16	21	23	15		9	1194	2132
10	12	13	16	17	29		12	1726	2474
29	14	16	19	20	11	11	9	1352	1543

Concrete for masonry blocks differs from cast-in-place concrete because, a zero slump mix is required unlike cast-in-place concrete which the slump is typically a specified value. The curing of concrete masonry blocks also differs from cast-in-place concrete. In general, concrete blocks are cured in a moisture controlled environment and cast-in-place concrete is cured in place. In addition, the fabrication of concrete blocks utilizes a vibropress method of vibration to consolidate the concrete into the mold. For Amiri's study the Phase 1 cylinders were compacted to the ASTM D678-78 standard for soil compaction.

Materials required to make a concrete block mix include cementitious material, aggregates, and water. Admixtures are sometimes used to help the mix achieve different characteristics. Materials used for the Amiri's study ranged in size from 3/8-inch to 0-inch (9.5-mm to 0-mm) A Sieve analysis was conducted according to ASTM D546-88 to sort each aggregate into the categories.

In Amiri's study, the mixing of design mixtures for Phase 1 was typically performed manually because of the small amounts of mixture needed to fabricate the proctor cylinders. Due to the simplicity of the method and utilization of the volumetric procedure for the block fabrication site, mixture amounts were determined by the volumetric proportioning procedure.

The weight method, also available for proportioning produces a more accurate mixture although the difference is inconsequential.

For the second phase of Amiri's study the mixture was determined by the optimized mixture design concluded from Phase 1 of the study. Specimens for the second phase were initially produced by a block-making machine in Amiri's laboratory and then produced in a plant production facility. Various sizes of Phase 1 proctor cylinders to the blocks may have caused some strength variations. Results from Phase 2 of Amiri's study are given in Table 3.2.

Table 3.2 Concrete Block Mix Designs (Percentages by Weight) for Amiri Study

Mix. No.	Aggregate (lbs.)			Cement (lbs.)	Fly Ash (lbs.)	Strength at 28 days	
	Coarse	Medium	Fine			Block	Cylinder
1	740		901	462	528		2056
2	740		901	462	528		
3	740		901	462	528		2858
4	740		901	462	528	3862	4339
5	832		1013	462	265	3218	4029
6	257	1442	289	330	252	2756	2253
7		2000		594		2731	3073
8		1800	200	462	300	1831	
9		1500	500	462	300	2535	
10		1500	500	462	200	2194	
11		1500	500	462	200	3388	

Test results from Amiri's study determined that use of a minimum void gradation and a maximum aggregate size of 1/4-inch. (6.4-mm) allow a lightweight high-performance economical concrete masonry block to be obtained. The research team also determined to conduct additional research on the use of different aggregates in lightweight concrete blocks. Mix designs from this research study provided a preliminary concrete design used for concrete masonry units with plastic bottle cores.

Compressive Strength Test for Low-Strength Cement Blocks

The increased use of concrete masonry units in construction in the 1990s created a necessity for a standard for compressive strengths was in the country of Sri Lanka. Sammu Raghu De Silva Chandrakeerthy completed a study called *Compressive Strength Test for Low-Strength Cement Blocks* (1991) in which he analyzed several different standards for compressive strength testing. The purpose of the study was to determine if the current standard testing method was adequate or if changes were necessary. Chandrakeerthy determined that a standard for testing needed to be established because of several factors that compressive strength has for concrete masonry blocks. First, the compressive strength value for concrete blocks is crucial because it determines other properties of the concrete block. Second, the compressive strength value is more utilized than other test values for concrete blocks. Chandrakeerthy's study also investigated the importance of capping material used for the block and how the material affects compressive strength results.

Chandrakeerthy created a test method that utilized a loading method shown in Figure 3.1. The load was applied at any convenient rate to approximately half the expected maximum load, and the remaining load was applied at a uniform rate in no less than 2 minutes.

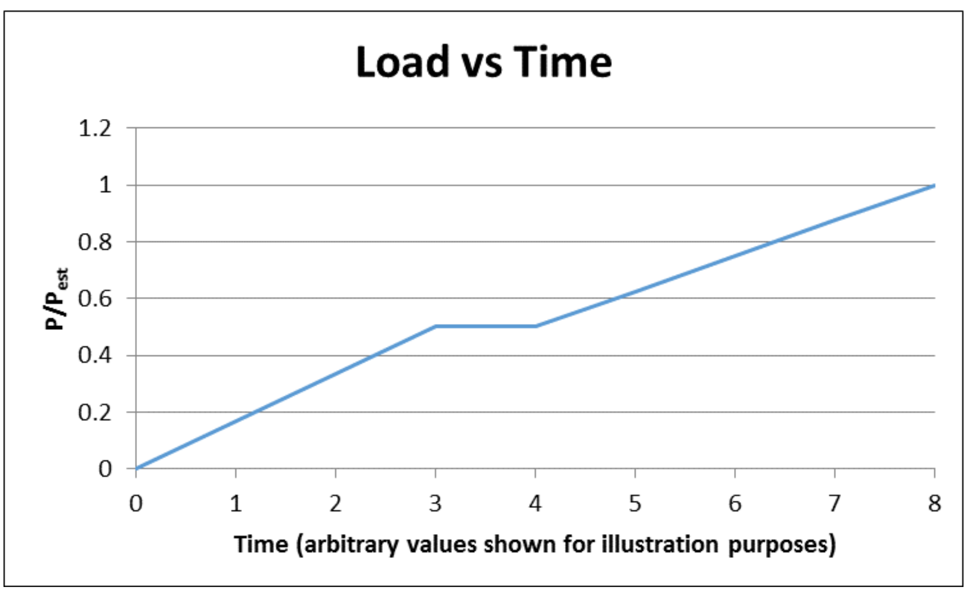

Figure 3.1 Loading Curve

Chandrakeerthy's loading rate was different than the ASTM C140 standard used for compressive strength testing of specimens in this research study because, the second half loading rate was lower and provided a longer time before failure.

Chandrakeerthy determined that four test methods would be used for the study. The first method was the Sri Lankan standard method (M3), and the second method (M1) utilized a capped block without packing because it provided highest strength results. The second method used a mortar capping method because the sulfur capping method was expensive and hazardous because of toxic fumes. The third method (M2) for the study utilized an uncapped block with packing to provide uniform stress distribution. The final test method (M4) used a weaker capping material, one cement: two sand with water-cement ratio of 0.4 with no packaging. In addition to the four test methods, the study utilized three main test series with corresponding sub-test series. The Test Series B tested the effect of mix proportions of hollow blocks with constant block size on various test methods. Test Series B specimens are shown in Table 3.3.

Table 3.3 Test Series B for Chandrakeerthy Study

Test Series	Specimen Code	Mix Proportions
B1	B11	One Cement: Six Sand: Four Quarry Dust
B1	B12	One Cement: Four Sand
B1	B13	One Cement: Three Sand: Six Aggregate (13 mm)
B2	B21	One Cement: Six Sand: Four Quarry Dust
B2	B22	One Cement: Three Sand: Six Aggregate (13 mm)
B3	B31	One Cement: Six Sand: Four Quarry Dust
B3	B32	One Cement: Three Sand: Six Aggregate (13 mm)

Test specimens were then analyzed using the four test methods. Sample sizes for each test specimen code were 10 tests each. To reduce material inconsistency for each specimen, the manufacturer shipped only blocks from the same batch, thus minimizing inconsistency within blocks that could affect test results. Specimens with code B12 were most similar to specimens analyzed in the research study produced for this paper. Results from these specimens are shown in Table 3.4.

Table 3.4 Results for Specimen B12 for Chandrakeerthy Study

Specimen Code	Test Method	Compressive Strength (lb/in^2) (N/mm^2)			
		M1	M2	M3	M4
B12	Average Value	1835 (12.65)	1851 (12.76)	1939 (13.37)	1751 (12.07)
B12	Standard Deviation	2.32	2.16	2.58	1.23
B12	Coefficient of Variation	18.37%	16.93%	19.3%	10.15%

Chandrakeerthy's study determined that a mortar mix of one cement: two sand by volume with a water-cement ratio of a maximum of 0.4 is adequate to cap blocks. The higher average of compressive strength given from test method M1 is unrealistic for low-strength concrete blocks due to end restraints that are achieved because of higher strength capping which will not be achieve in practice due to the lower strength mortar used in construction for low-strength concrete blocks.

Concrete Blocks with Ecological Aggregates

Concrete masonry units are beginning to utilize ecological aggregates. These concrete masonry blocks are beneficial to study because of the impact that a material not usually used in the concrete block could affect the behavior of the concrete block. A study conducted by Douglas C. Stahl, Gregg Skoraczewski, Phil Arena, and Bryant Stempski titled *Lightweight Concrete Masonry with Recycled Wood Aggregate* (2002) utilized recycled wood in the concrete masonry unit. Concrete masonry units studied in this research were tested to determine if compressive strengths met the ASTM C129 standard.

One primary issue addressed by this research was the incompatibility of wood and cement due to conflicting chemical properties of each material. Two main chemical incompatibilities are the presence of varying amounts of sugars in wood that act as retarders for cement and the presence of hemicellulose in wood that may reduce cement paste strength by reducing the cement hydration rate. Many case studies conducted before Stahl's study showed that washing the wood in hot water before using it as an aggregate may reduce incompatibility issues between wood particles and cement. However, chemical incompatibility present at the beginning of the hydration process may continue throughout the life of the concrete block, and, the cement producing acid may deteriorate the wood particles and decrease the ductility and strength of the block.

Stahl's study utilized laboratory trials conducted using cylinder tests. The concrete was mixed with a 12-quart (11.4-L) lab mixer and placed into test cylinder molds. The cylinders were formed using three lifts and each lift was tapped. The cylinders were then vibrated, compressed using a hand compressor, cured in one curing tank for 24 hours, and placed in a second curing tank for the remaining 27 days. This process differs from the in-plant procedure, but it allows controlled comparison for future research. After the laboratory tests, Stahl conducted a plant-produced unit test. The production process was similar to the process for standard concrete masonry units.

Chapter 4 - Test Plan and Procedure

Research conducted for this report was conducted in two phases: concrete mix design and concrete masonry units.

Concrete Cylinders

Concrete cylinders were fabricated in order to determine the compressive strength of concrete used in concrete masonry units. The cylinders were fabricated at the same time as the concrete masonry units.

Test Specimens

The compressive strength test of the concrete cylinders utilized six test cylinders. The test cylinders were fabricated from the same concrete batch used to fabricate the concrete masonry units. Three cylinders were created from each batch of concrete mix to determine the compressive strength of concrete without plastic bottles. Table 4.1 shows the fabricated test cylinder specimens.

Table 4.1 Test Cylinders

Specimen	Batch
T1	1
T2	1
T3	1
T4	2
T5	2
T6	2

Fabrication Procedure

Concrete mix was created using a 10-ft^3 (283.2-L) concrete mixer. The concrete mix design is identical to the mix design used for the concrete masonry units, as shown in Table 4.2.

Table 4.2 Concrete Mix Design

Percentage of Weight for Concrete Mix		
Sand	Cement	Water
75	17	8

Mason sand and Portland Type I/II were the types of sand and cement used for the mix design, respectively. Standard 4-inch diameter by 8-inch high (101.6-mm diameter by 203.2-mm) test cylinder molds were used to fabricate the cylinders, which were created in three lifts; each lift was vibrated with an electric concrete vibrator. The entire cylinder fabrication process for each batch took 10 minutes. The cylinders remained in the mold for 48 hours at a temperature of 75 ± 15°F (24 ± 8°C). After the 48 hours, the molds were removed and the cylinders placed in a moisture room at a temperature of 73 ± 3°F (73 ± 2°C) and a humidity of 100%. The moisture room was utilized to provide a controlled environment for curing and to allow all of the cement to hydrate in the mix. The concrete masonry units were cured using the same procedure.

Apparatus

Peak load tests were used to determine the compressive strength of concrete cylinders. The apparatus used for the test is shown in Table 4.3 and Figure 4.1. The test machine that was used for the loading was the Forney Machine which can apply a maximum load of 250 kips (1112 kN) with an accuracy of ± 1%. To provide a uniform surface on the top and bottom of the cylinders a sulfur cap was applied to the concrete cylinders.

Table 4.3 Test Apparatus for Cylinder Testing

Apparatus	Description
Forney Machine	Machine can apply loads up to 250 kips (1112 kN). It operates at a constant force and has an accuracy of ± 1% when calibrated. Last calibrated 1-27-10. See Figure 4-1
Sulfur Cap	Sulfur cap applied to concrete cylinders to allow for a uniform stress distribution.

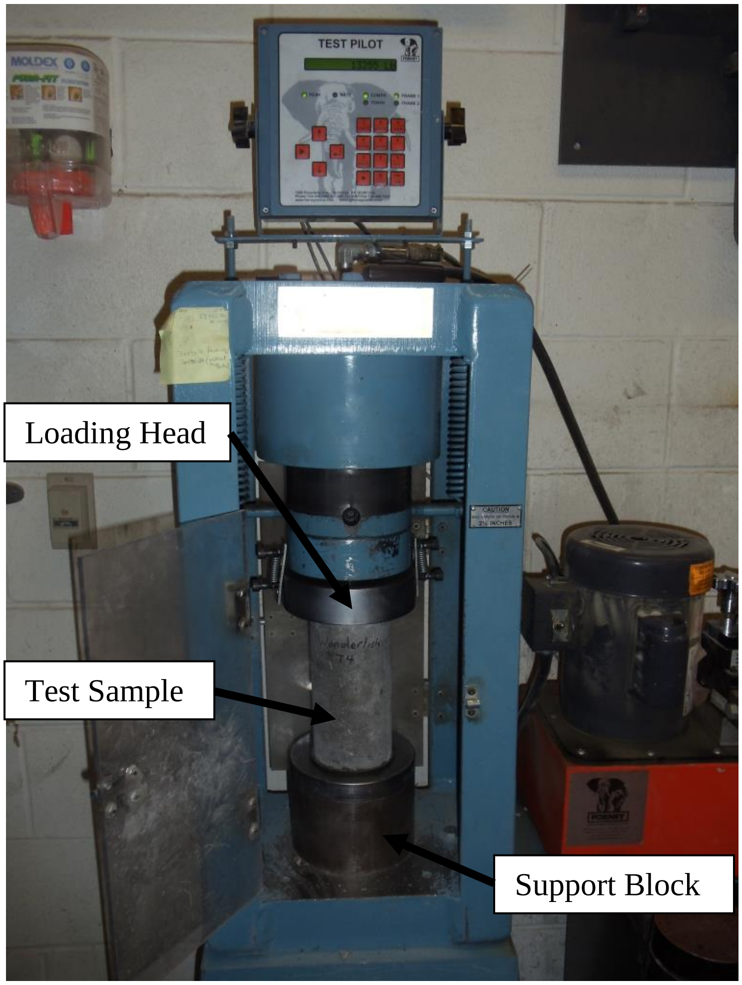

Figure 4.1 Test Cylinder Set-Up

Experimental Procedure

Test cylinders were tested to determine a compressive strength. The testing was conducted following ASTM C39 *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.* This was conducted by loading the test cylinders at a constant load rate of 420 lb./sec (1868 N/sec). Peak load from this loading was determined from the test apparatus, and then the peak load was used to determine the compressive strength of the concrete cylinder. The average compressive strength was used to determine estimated peak loads for the concrete masonry units, allowing a calculation for the load rate needed for the second half of the concrete masonry unit load tests.

Concrete Masonry Unit

The concrete masonry units used for this study are 7.87-inch wide by 8.26-inch high by 15.75-inch long (200-mm wide by 210-mm high by 400-mm long) with an allowance of ± 0.2-inch (5-mm). The web thickness is 1.0-inch (25.4-mm) with an allowance of ± 0.2-inch (5-mm). The plastic bottles will create the voids of the masonry units with four plastic bottles forming each of the voids. This study follows the ASTM C140 *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units* for the procedure of the testing.

Test Plan

The compressive strength test of the concrete masonry units comprised of five test series. Each test series was created using the same concrete design for the concrete masonry units with plastic bottles filling the cores. Test specimens were identical in shape and size. Table 4.4 presents the various materials used for each test series. Concrete masonry units were tested using the five brand names of the plastic bottles being Dasani, Aquafina, Ozarka, Nestle, and Great Value.

Table 4.4 Test Series

Series	Test Combinations	
	Brand Name of Bottle	Number of Bottles
1	Dasani	8
2	Aquafina	8
3	Ozarka	8
4	Nestle	8
5	Great Value	8

The shape and size of the test specimens was determined by the nominal size used for concrete masonry units in the construction of walls. The 7.87-inch wide by 8.26-inch high by 15.75-inch long (200-mm wide by 210-mm high by 400-mm long) with an allowance of ± 0.2-inch (5-mm) size used is the standard size of concrete masonry units used in the construction of walls. Therefore, in order to imitate typical construction, the test was limited to one shape and size of concrete masonry units. Materials used for testing are presented in Table 4.5.

Table 4.5 Materials for Tests

Materials	Description
Portland Cement	Portland cement type I/II
Sand	Mason sand
Plastic Bottle	16.9 oz. (500-mL) plastic bottles
Gypsum Cement	Hydro-Stone gypsum cement

Each test series utilized three test specimens to obtain sizable data and each test specimen used a total of eight plastic bottles to fill the two cores of the masonry unit. For each test series, a different plastic bottle manufacturer was used.

Test specimens comprising the five different test series were labeled with the test series number followed by a letter. Test Series 1 specimens utilize Dasani as the water bottle brand with Test Series 2 specimens utilizing Aquafina as the water bottle brand. Test Series 3, 4, and 5 utilize Ozarka, Nestle, and Great Value respectively as the water bottle brand. Table 4.6 presents the test specimen label and brand used.

Table 4.6 Concrete Masonry Unit Specimens

Test Series	Specimen Label	Brand of Plastic Bottle
1	1A	Dasani
1	1B	Dasani
1	1C	Dasani
2	2A	Aquafina
2	2B	Aquafina
2	2C	Aquafina
3	3A	Ozarka
3	3B	Ozarka
3	3C	Ozarka
4	4A	Nestle
4	4B	Nestle
4	4C	Nestle
5	5A	Great Value
5	5B	Great Value
5	5C	Great Value

Apparatus

Peak load tests were used to determine compressive strength of the concrete masonry units. Apparatus used for the test are shown in Table 4.7 and Figures 4.2 and 4.3. The Baldwin Turret Press is the machine used to apply the loading to the specimens. It can apply a maximum load of 400 kips (1779 kN) with an accuracy of ± 1%. The size of the load head on the Baldwin Turret Press is smaller than the concrete masonry units so a loading plate is used to distribute the load uniformly to the masonry unit. A 1-inch (25.4-mm) steel plate is used for the loading plate. To allow for a uniform surface on the top and bottom surfaces of the masonry units a gypsum cement cap was used.

Table 4.7 Test Apparatus for Concrete Masonry Unit Testing

Apparatus	Description
Baldwin Turret Press	Machine can apply loads up to 400 kips (1779 kN). It operates at a constant force and has an accuracy of ± 1% when calibrated. Last calibrated 3-21-11. See Figure 4-2.
Loading Plate	1-inch (25-mm) steel plate to distribute the load evenly to the cross section of the specimen from the Baldwin Turret Press. See Figure 4-3.
Gypsum Cement Cap	Hydro-Stone gypsum cement cap to provide a uniform surface on the top and bottom surfaces of the concrete masonry unit.

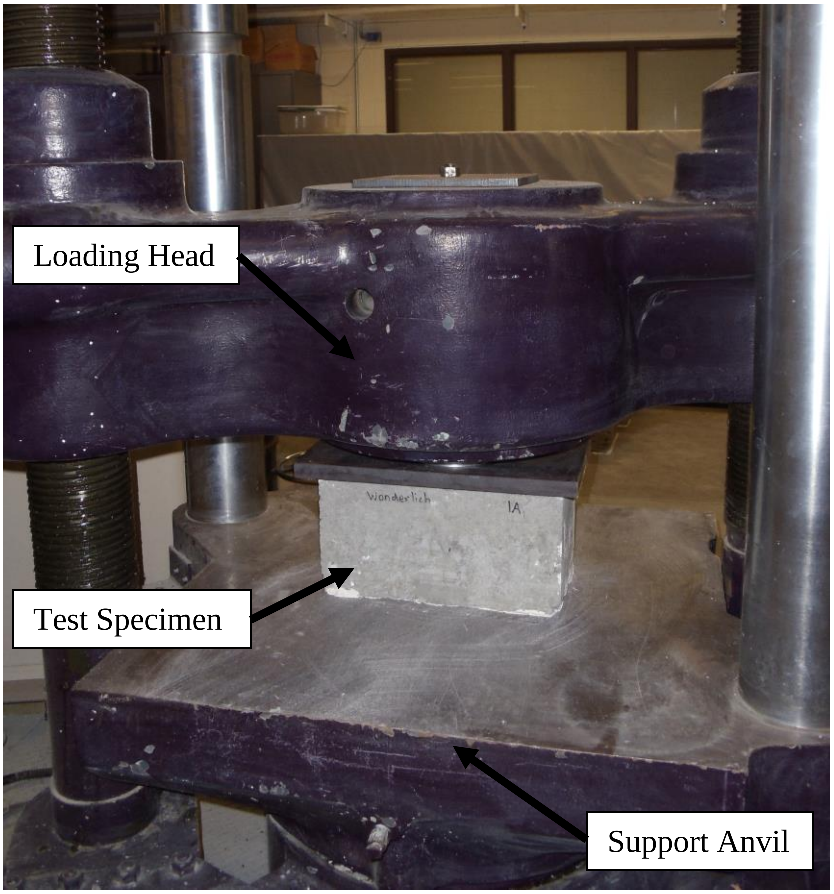

Figure 4.2 Baldwin Turret Press Machine

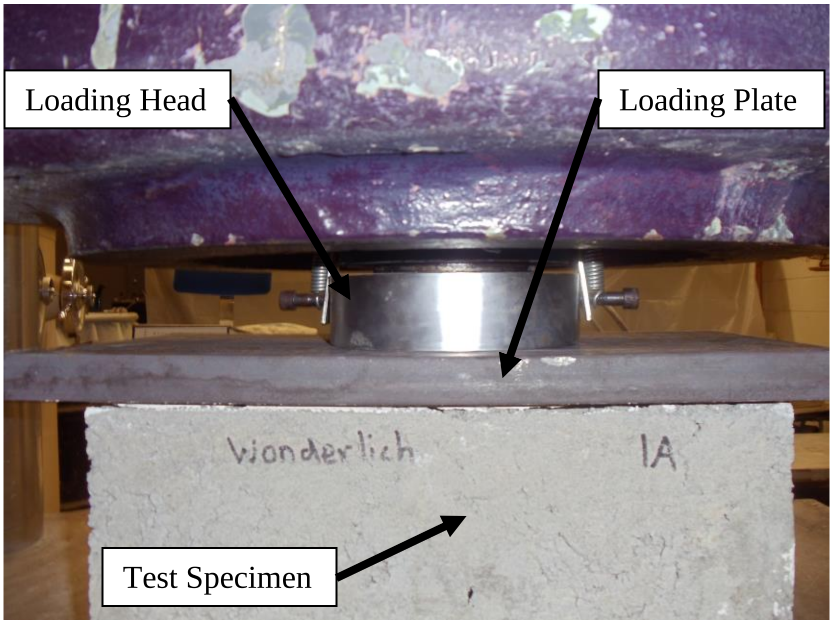

Figure 4.3 Loading Plate

Fabrication Procedure

Test specimens used in the experiment were fabricated in the Civil Engineering Concrete Lab at Kansas State University before experimental testing. Therefore, the first portion of the procedure created the concrete masonry units. Table 4.8 shows the concrete mix design used in the fabrication of the concrete units. The percentages of weight for the concrete mix were determined to be 75% of the weight for sand, 17% of the weight for cement, and 8% of the weight for water. With these percentages the actual amounts of sand, cement, and water for each batch was determined.

Table 4.8 Concrete Mix Design

Percentage of Weight for Concrete Mix		
Sand	Cement	Water
75	17	8

Test specimens were cast in specimen with molds assembled of ½-inch (12.7-mm) thick plywood. Four plastic bottles filled each of the two cores of the masonry unit. A top brace was placed onto the mold to secure the plastic bottles in the correct location. The concrete mix using a 10-ft^3 (283.2-L) concrete mixer and then poured to fill one-third of the mold. The concrete was vibrated into an even spread from an electric concrete vibrator. Additional concrete was placed on top of the even spread to two-thirds full and the vibration was repeated to create an even spread. At this point, the top brace for the bottles was removed and the remaining third of the mold was filled with concrete. The concrete was then hand-tapped to form an even spread and uniform top for the concrete masonry unit. The entire process, from the end of mixing until the last concrete unit was poured, lasted 45 minutes. The concrete masonry units were stored in the mold in a room with a temperature of 75 ± 15°F (24 ± 8°C) for 48 hours then removed from the mold and placed in a moisture room of 100% humidity and a temperature of 73 ± 3°F (73 ± 2°C) for the remaining 27 days of the curing process. Figure 4.4 shows the test specimen set-up.

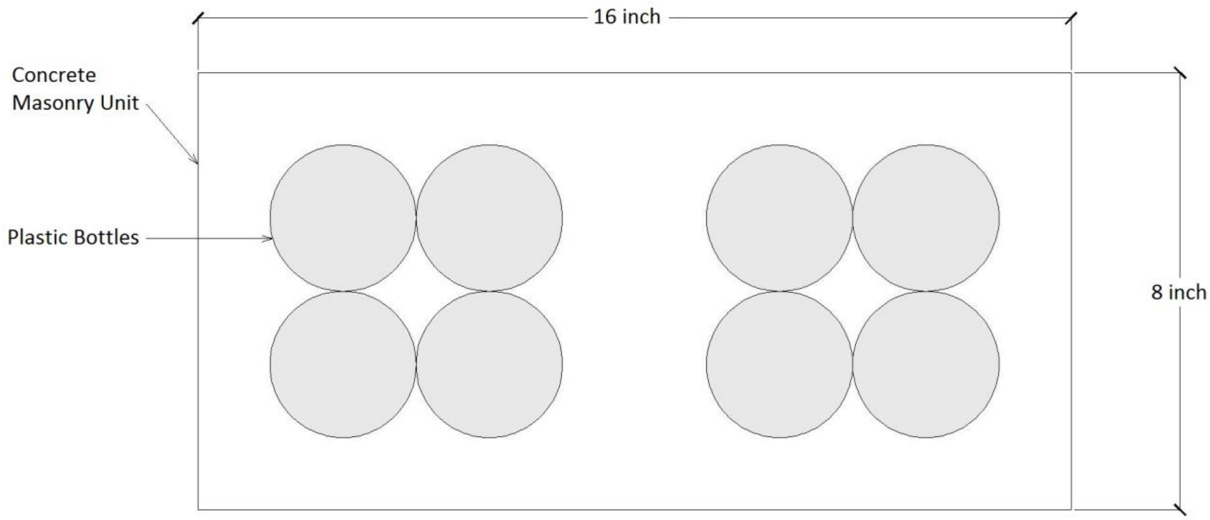

Figure 4.4 Test Specimen Set-Up

A sample of concrete masonry unit specimens are shown in Appendix A. All sides of the specimen are shown.

Test specimens must be capped according to the ASTM standard C1552 *Standard Practice for Capping Concrete Masonry Units, Related Units and Masonry Prisms for Compression Testing.* This standard requires the use of either high strength gypsum cement or sulfur for the capping material. For this thesis, high strength gypsum cement called Hyrdo-Stone was used as the capping material. The procedure for the capping process is as follows:

1. Preparation of Specimens for Capping – use an abrasive stone to remove loose protrusions from specimen surfaces.
2. Spread the gypsum cement evenly of the capping plate lightly coated with oil.
3. Bring the specimen surface into contact with the capping material; firmly press down on the specimen, holding it so that the axis is at right angles to the capping surface.
4. Leave the specimen undisturbed until the capping material has solidified.

The caps must be perpendicular within 0.08-inch (2.032-mm) in 8-inch (203.2-mm) to the vertical axis of the specimen, and the surface of the cap must be in plane within 0.002-inch (0.051-mm) in any 12-inch (304.8-mm) span of the surface. Average thickness of the capping material must also be less than 1/8-inch (3.2-mm). Once capped, the specimens are ready to begin the experimental procedure.

Experimental Procedure

Before beginning a test, the concrete masonry unit was removed from the moisture room and placed in a room of 75 ± 15°F (24 ± 8°C) with a relative humidity of less than 80% for two days, thus preventing the unit from having any visible moisture on the surface at the time of testing. The specimen was secured in the Baldwin Turret Press but not loaded by the machine. The specimen was then loaded, following the procedure listed below until failure to determine the ultimate load.

For the first series, a pre-test specimen was loaded to failure to determine ultimate load for the remaining test series. This test procedure was based on the ASTM C140 *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units* procedure. For this procedure there are two loads that will need to be known or determined. The ultimate load, P_u, is the load at which failure occurs. The estimated load, P_{est}, is the other load and this load is the estimated load of which failure will occur. The procedure is as follow:

1) Conduct a preliminary test to determine ultimate load in order to set up proceeding tests. The ultimate load, P_u, is defined as the load corresponding to specimen failure.

2) Estimate the load at which failure will occur in future specimens, P_{est}, based on the ultimate load, P_u
3) Apply load according to ASTM C140 as follows:
    i. Apply load until it reaches $0.5*P_{est}$
    ii. Adjust machine controls to ensure a uniform rate of travel
    iii. Apply remaining load at a uniform rate to reach failure in not less than 1 minute and no more than 2 minutes
4) Compare ultimate load, P_u, to the estimated load, P_{est}. The ultimate load is the load at which failure occurs. The first specimen should not be discarded as long as the ultimate load was reached after 30 seconds of the second loading.
5) Determine the gross area compressive strength.

The load curve as described in Step 3 above, is shown in Figure 4.5. Step 3i is shown from time 0 to 3 and, Step 3iii is shown from 4 to 6.

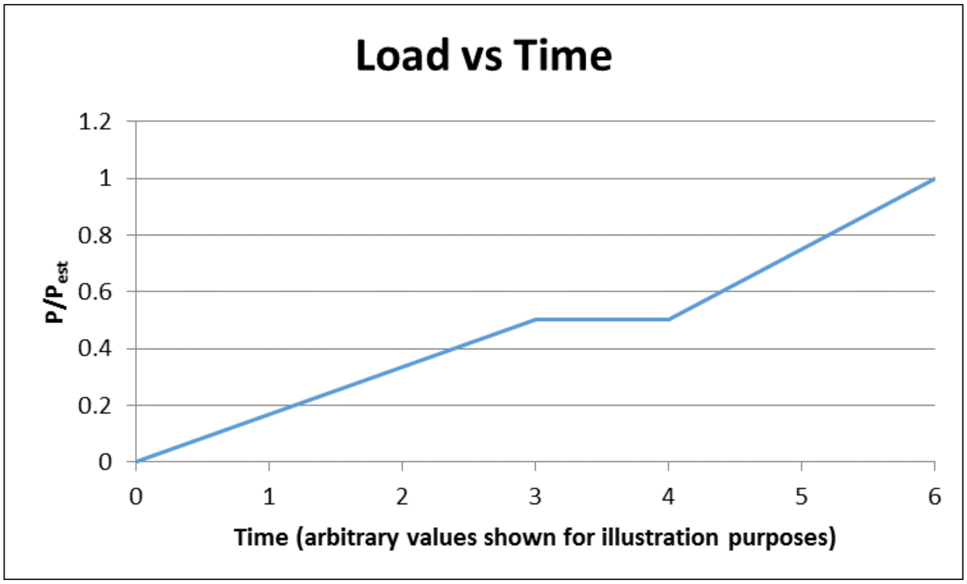

Figure 4.5 Loading Curve

Chapter 5 - Test Results

Test Data

Data collected from each test series is shown in Tables 5.1 and 5.2. Table 5.1 shows the results from the cylinder testing. The 6 different specimens are each labeled T1 through T6. The average diameter is determined by measuring the diameter of the cylinder on the top surface and bottom surface. Area of the cylinder is then determined from the average diameter for each cylinder. Peak load is given by the Forney machine for the ultimate load at which failure occurs. Peak load is given with an accuracy of ± 1%. The compressive strength of each cylinder is determined by taking the peak load of the cylinder and dividing it by the area of the cylinder. This compressive strength is then used to determine the estimated load of failure for the concrete masonry units.

Table 5.1 Test Results from Cylinder Tests

Test Cylinder Strength				
Specimen	Average Diameter (in) (mm)	Area (in^2) (mm^2)	Peak Load (lb) (N)	Compressive Strength (psi) (MPa)
T1	4.01 (101.8)	12.63 (8148)	12550 (55825)	990 (6.8)
T2	3.99 (101.3)	12.50 (8064)	10810 (48085)	870 (6.0)
T3	3.99 (101.3)	12.50 (8064)	7455 (33161)	600 (4.1)
T4	4.02 (102.1)	12.69 (8187)	16025 (71283)	1260 (8.7)
T5	4.01 (101.8)	12.63 (8148)	13255 (58961)	1050 (7.2)
T6	4.01 (101.8)	12.63 (8148)	18405 (81870)	1460 (10.1)

Table 5.2 shows the results from the concrete masonry unit testing. The 15 different specimens are labeled 1A through 5C. Specimen labeling is grouped by brand name of the bottles and then labeled for individual specimen. All of the specimens for 1A through 1C use the Dasani plastic water bottles while the specimens than begin with a 2 use Aquafina. The gross area of the masonry units was determined in accordance with ASTM C140 standard. The individual dimension measurements were specified were to be measured and the average width and length of each specimen was used to determine the gross area. Theoretical area was determined by finding the area of one bottle for each brand name would have. This value was then multiplied by 8 since there were 8 bottles per specimen and this now bottle area was subtracted from the gross area to determine the theoretical net area for each specimen. Peak load

for each specimen was determined from the Baldwin Turret Press for the ultimate load at which failure occurred. The peak load is given with an accuracy of ± 1%. The gross compressive strength is determined by taking the peak load of each specimen and dividing it by the gross area of each specimen. While the theoretical net compressive strength is determined by taking the peak load and dividing it by the theoretical net area for each specimen.

Table 5.2 Test Results from Concrete Masonry Unit Tests

Block Strength					
Specimen	Gross Area (in^2) (mm^2)	Theoretical Net Area (in^2) (mm^2)	Peak Load (lb) (N)	Gross Compressive Strength (psi) (MPa)	Theoretical Net Compressive Strength (psi) (MPa)
1A	123.72 (79819)	78.33 (50535)	49520 (220276)	400 (2.8)	630 (4.3)
1B	124.35 (80226)	78.97 (50948)	45270 (201371)	360 (2.5)	570 (3.9)
1C	123.64 (79768)	78.26 (50490)	40000 (177929)	320 (2.2)	510 (3.5)
2A	123.79 (79864)	82.54 (53252)	75990 (338020)	610 (4.2)	920 (6.3)
2B	123.56 (79716)	82.30 (53097)	109190 (485701)	880 (6.1)	1330 (9.2)
2C	123.01 (79361)	81.75 (52742)	67850 (301812)	550 (3.8)	830 (5.7)
3A	123.56 (79716)	82.30 (53097)	107450 (477961)	870 (6.0)	1310 (9.0)
3B	123.56 (79716)	82.30 (53097)	49950 (222189)	400 (2.8)	610 (4.2)
3C	124.19 (80122)	82.93 (53503)	87410 (388819)	700 (4.8)	1050 (7.2)
4A	122.69 (79155)	83.42 (53819)	71550 (318270)	580 (4.0)	860 (5.9)
4B	121.83 (78600)	82.56 (53264)	91510 (407057)	750 (5.2)	1110 (7.7)
4C	123.32 (79561)	84.05 (54226)	82860 (368580)	670 (4.6)	990 (6.8)
5A	126.48 (81600)	87.21 (56264)	82020 (364843)	650 (4.5)	940 (6.5)
5B	127.51 (82264)	88.24 (56929)	115250 (512658)	900 (6.2)	1310 (9.0)
5C	125.77 (81142)	86.50 (55806)	103840 (461903)	830 (5.7)	1200 (8.3)

Chapter 6 - Conclusion

Discussion of Results

The compressive strength both gross and theoretical net varied depending on the quality of the masonry unit. Lower compressive strength blocks had portions of face shells missing which decreased the amount of concrete used to resist loading. The quality of masonry units varied depending on how the concrete mix was vibrated into location and the amount of air voids present during the curing process.

In general, the test results reveal that plastic bottles which contain recycled plastic increased the compressive strength of the masonry unit. This is due to the fact that harder plastic bottles created an internal force against the face shells and pushed the shells outward, decreasing the area to be used in compression. In addition, the diameter of the bottles was greater, thus creating less net area for compressive force. This failure is demonstrated in Figures 6.1 and 6.2. In Figure 6.1 Test Specimen 1B which utilizes Dasani plastic water bottles is shown. The Dasani plastic water bottle utilizes a harder plastic than the Test Specimen 2C which is shown in Figure 6.2. Test Specimen 2C utilizes Aquafina water bottles which use already recycled plastic for the water bottle.

Figure 6.1 Specimen 1B Failure

Figure 6.2 Specimen 2C Failure

Figure 6.2 shows that the face shell in Test Specimen 2C cracked, consequently causing complete failure of the masonry unit although the face shell stayed intact. This resulted in a higher peak load and higher compressive strengths. The softer plastic of the bottle allowed the compressive force to crumple the bottle instead of adding internal pressure on the face of the masonry units. Figure 6.3 shows the specimens grouped by each brand name of bottle and a graph of the loading from zero load to the ultimate failure load is shown.

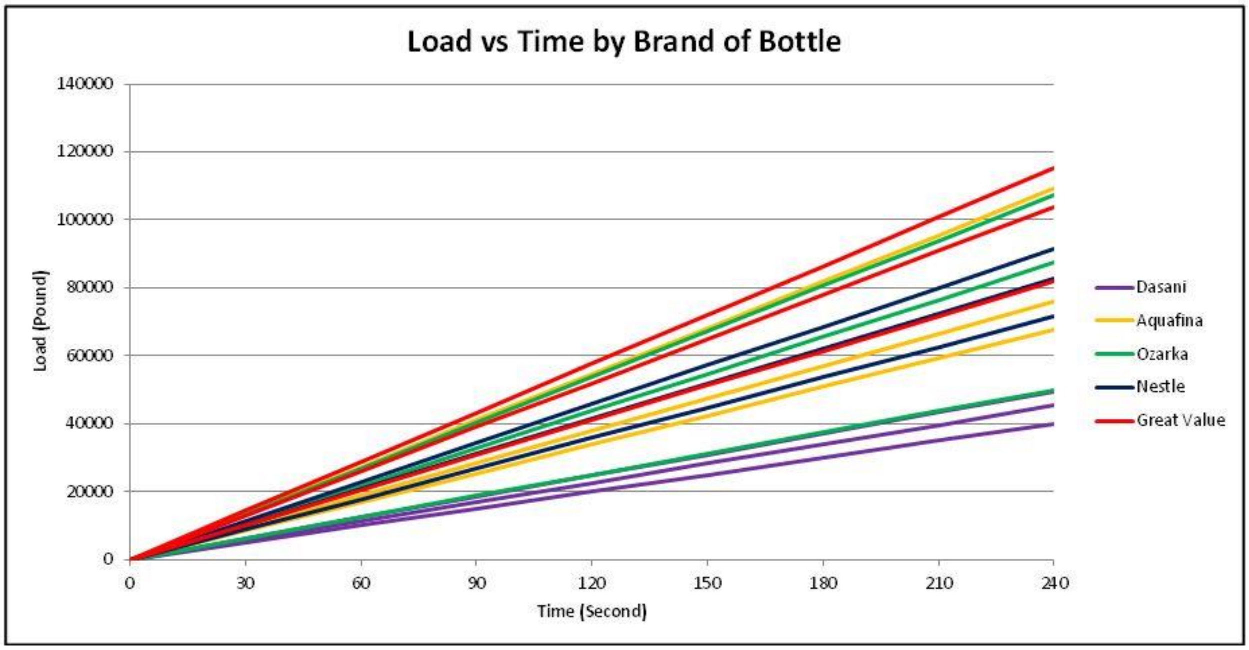

Figure 6.3 Load vs Time by Brand of Bottle

Figure 6.3 shows the specimens with Dasani plastic water bottles are grouped at the bottom of the ultimate load graph. This is because the failure mechanism for these bottles was brittle cleavage of the masonry units. Cleavage of the masonry units was influenced by the additional internal pressure created from the harder plastic water bottles being compressed for the loading head. This additional pressure forced the face shells outward which allowed for the cleavage of the concrete. The figure also shows that the specimens with the Great Value water bottles are at the top of the ultimate loads. These bottles utilize the recycled plastic for the plastic water bottles. This recycled plastic allowed for a lower internal pressure from the compression of the water bottles and allowed for the failure mechanism to be a brittle failure without cleavage of the concrete. Specimens that are in the middle group of the graph also have the recycled plastic for the plastic water bottles. These specimens although having a lower ultimate strength had the same failure mechanism as the Great Value specimens. The brittle failure of the masonry unit did not cause any cleavage of the concrete.

Conclusion

The use of concrete masonry units with plastic bottle cores could become possible in third world countries. Ease of masonry unit construction on-site was of utmost importance in the creation of the laboratory units. This was achieved by primarily using hand tools in addition to the concrete mixer. Compressive strength of the units was not drastically different than test cylinder results, confirming that masonry units can be used when the concrete mixture is determined to be adequate. Masonry units can be fabricated on the construction site and allowed to cure before being placed in the structure.

Limitations

The limitations of this study are as follows:

- Each material used was supplied from one source. While the materials are standardized, different storage methods may result in different strengths.
- The study intended to determine only the compressive strength of masonry units. The effects of unit deformation must also be considered.
- Only plastic bottles with lids were tested. Further tests using bottles without lids may result in different strengths.
- The number of tests per specimen series was small. In order to narrow the average compressive strength, more units per specimen series should be tested.

Recommendations for Further Research

Further study should be conducted to support the values determined as the compressive strength of these concrete masonry units. In addition, expanding the variety of bottle types used in the masonry units is suggested. Mixing the various types of plastic bottles in the same masonry unit is also suggested to determine if affects compressive strength. Other variables to study further include, but are not limited to, the number of plastic bottles per masonry unit, the height of the plastic bottles, whether the bottles have lids, and the orientation of the bottle (lid side up or down).

Further study should also include testing different categories of the masonry unit besides compressive strength. Testing should include thermal conductivity of the masonry unit. Does the addition of plastic bags inside the plastic bottle increase resistance to heat change? Further analysis of shear loading and cyclic loading on the masonry units is suggested to analyze the masonry unit for seismic loading.

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Appendix A - Concrete Masonry Unit Specimens

Concrete masonry unit specimens before capping and compressive strength testing.

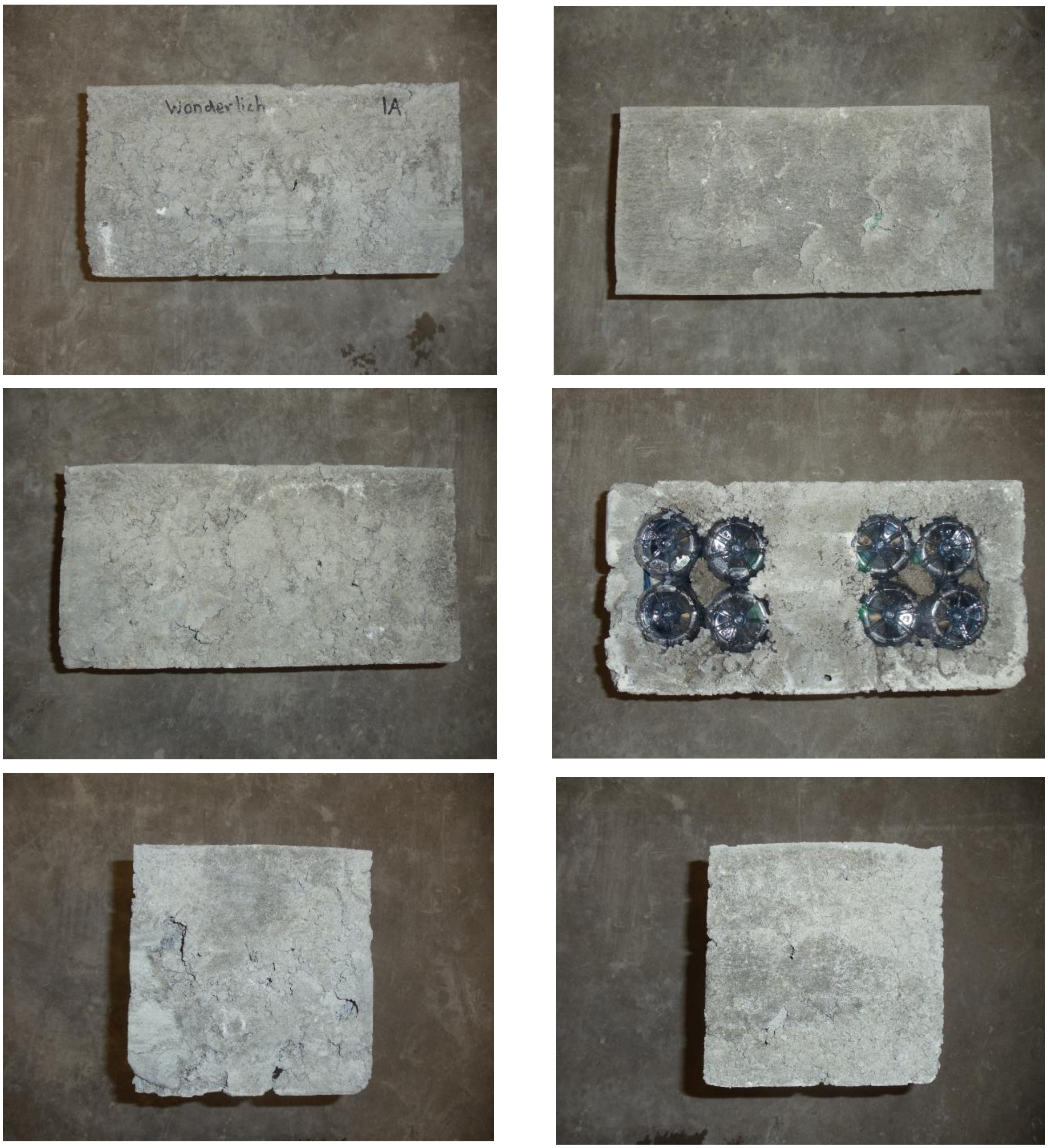

Figure A.1 Specimen 1A

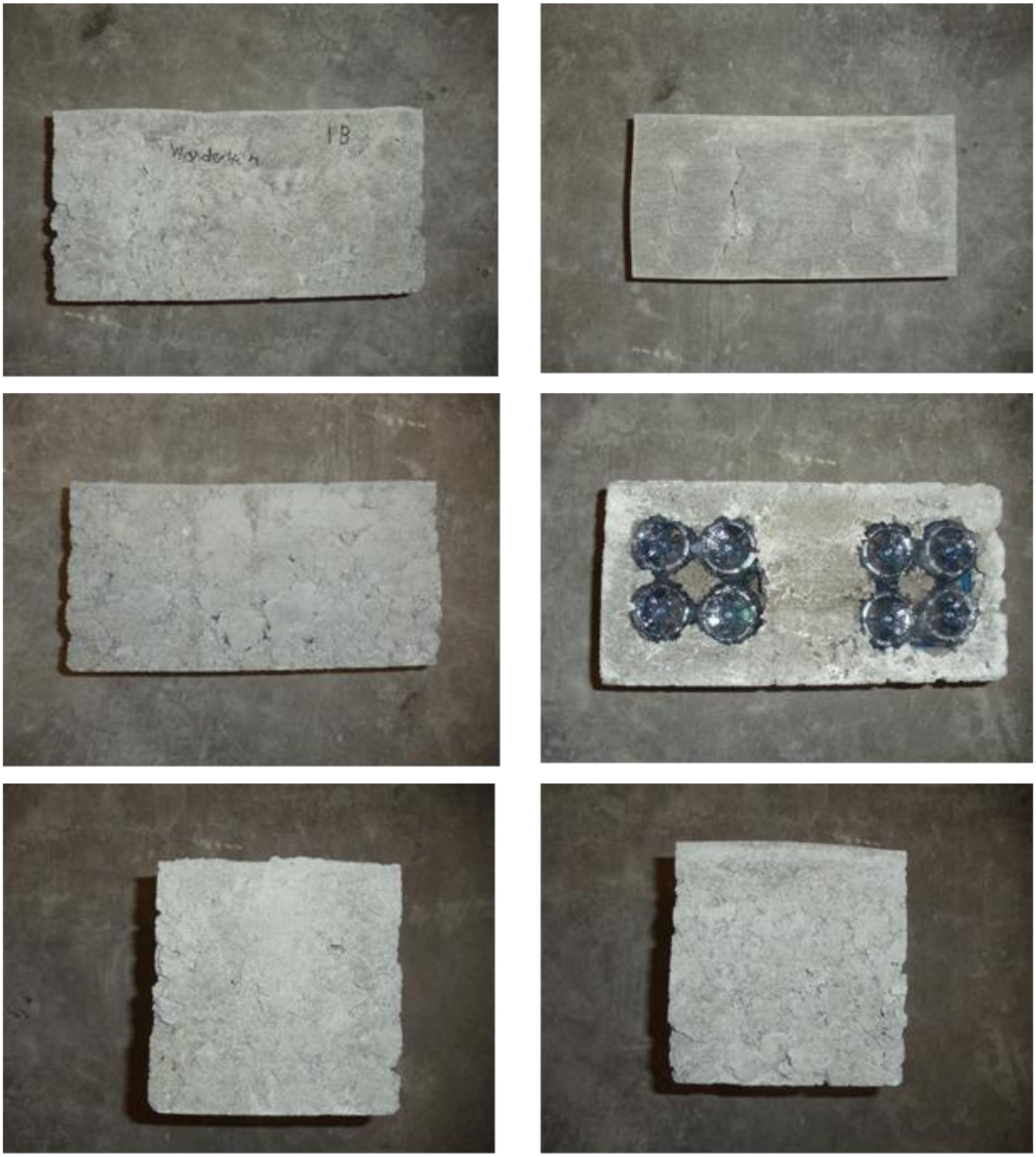

Figure A.2 Specimen 1B

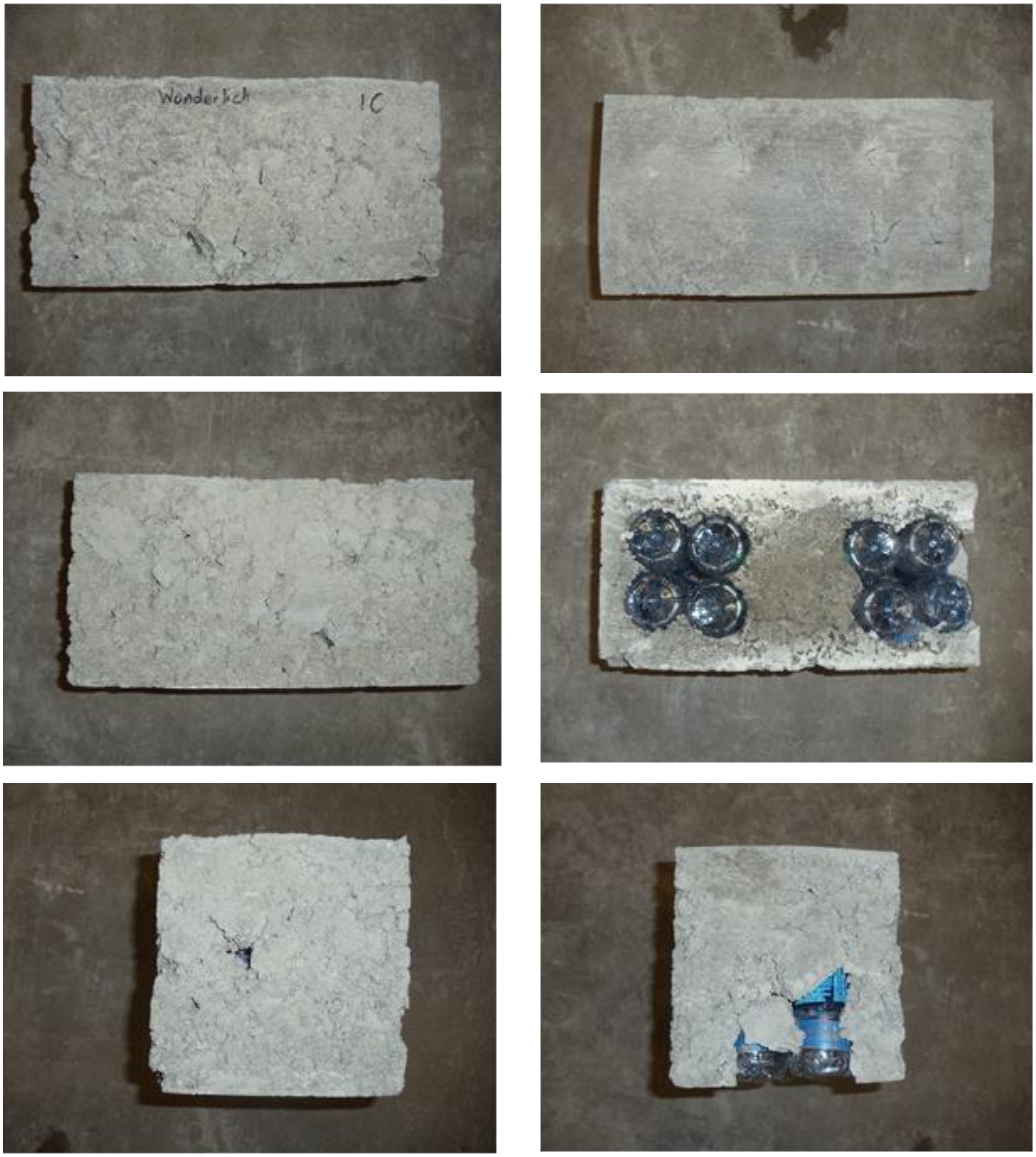

Figure A.3 Specimen 1C

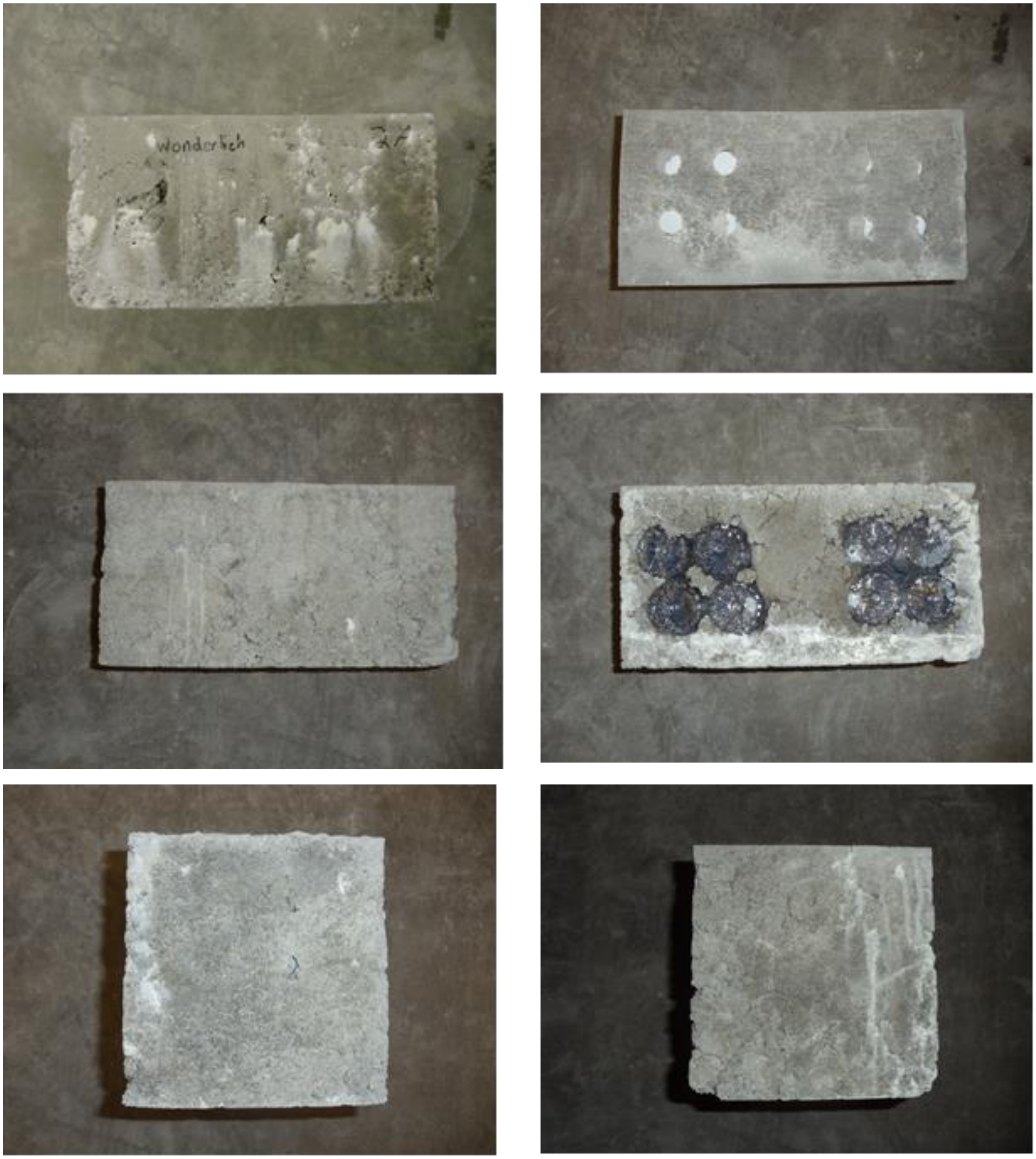

Figure A.4 Specimen 2A

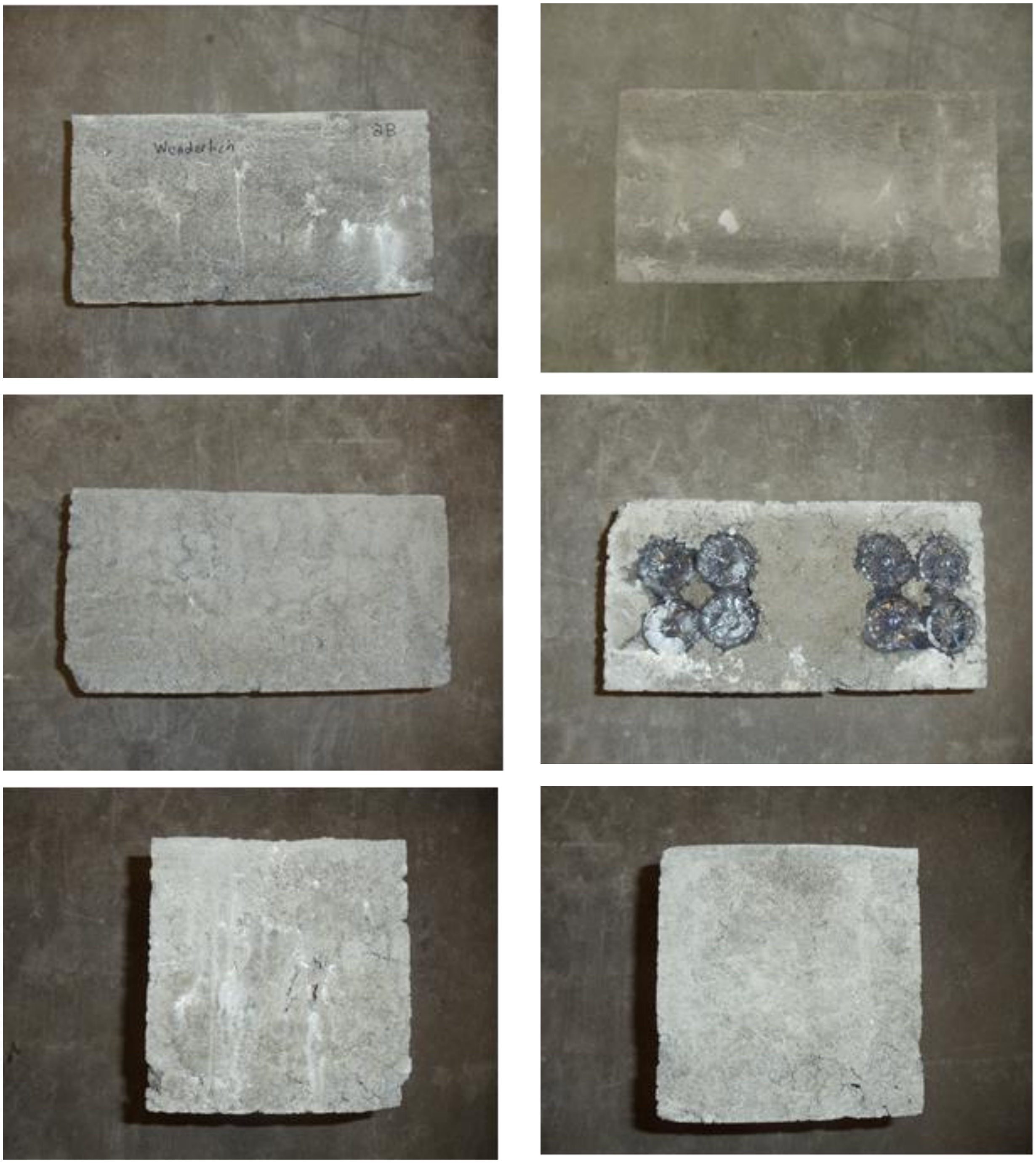

Figure A.5 Specimen 2B

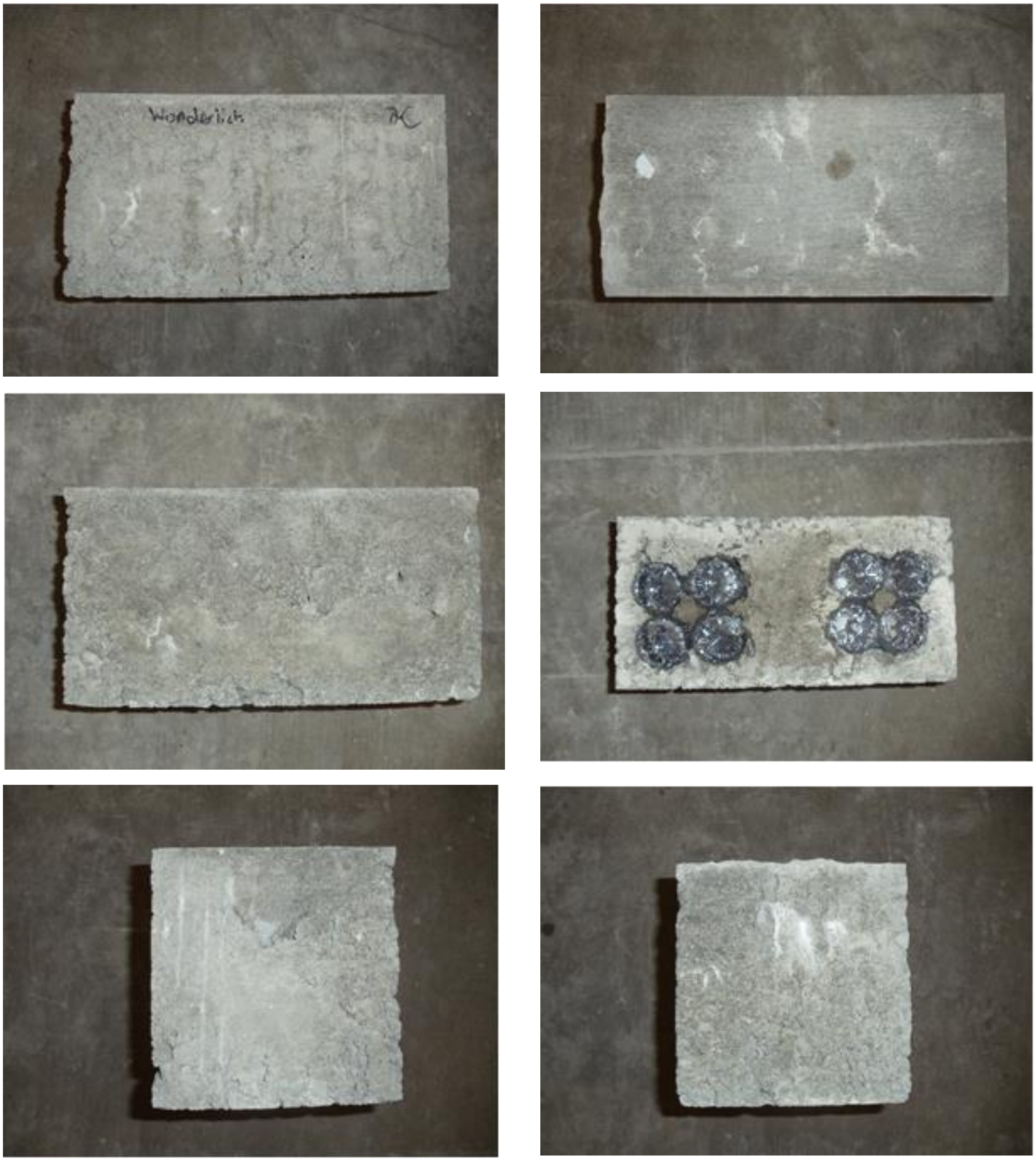

Figure A.6 Specimen 2C

Figure A.7 Specimen 3A

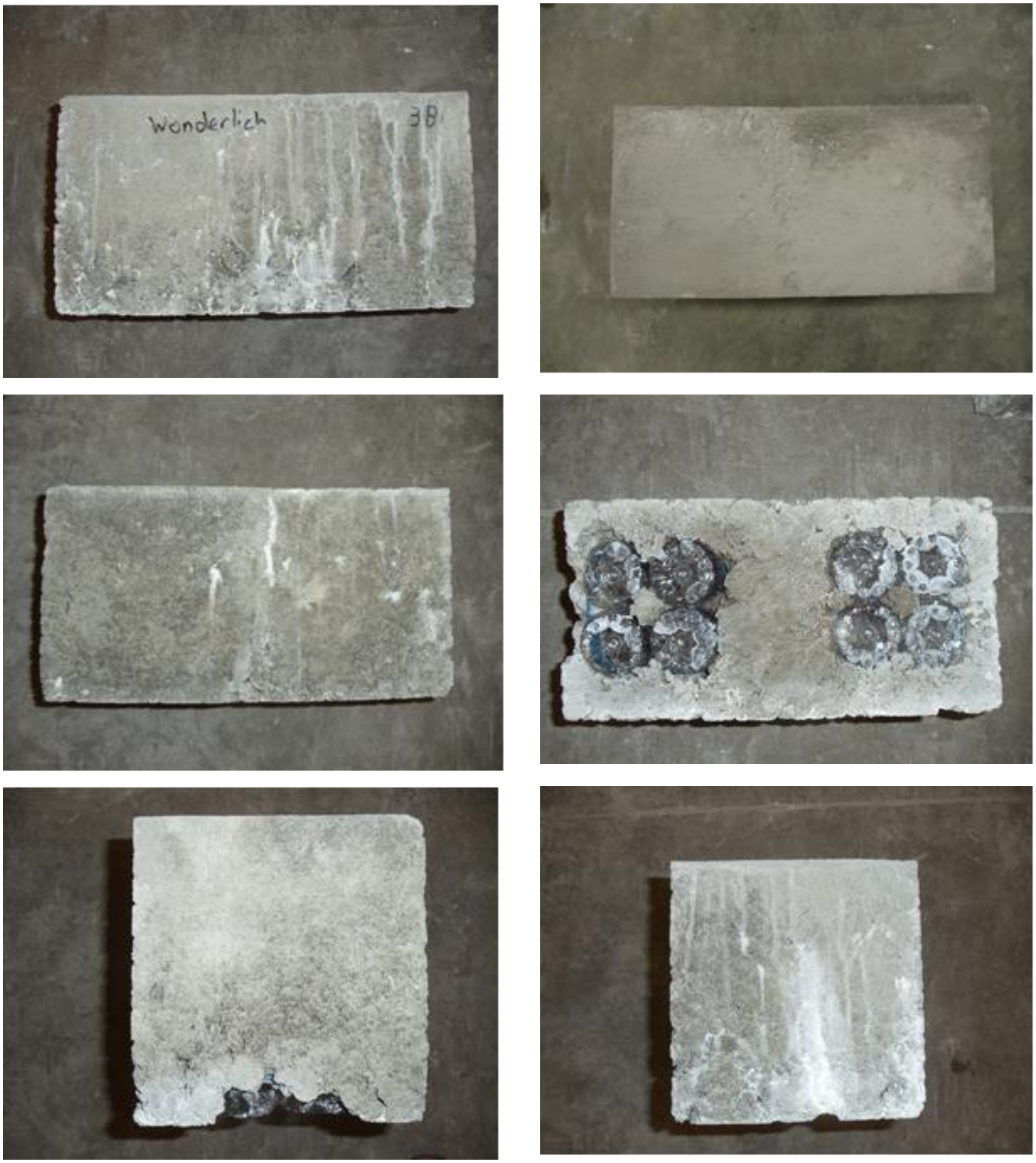

Figure A.8 Specimen 3B

Figure A.9 Specimen 3C

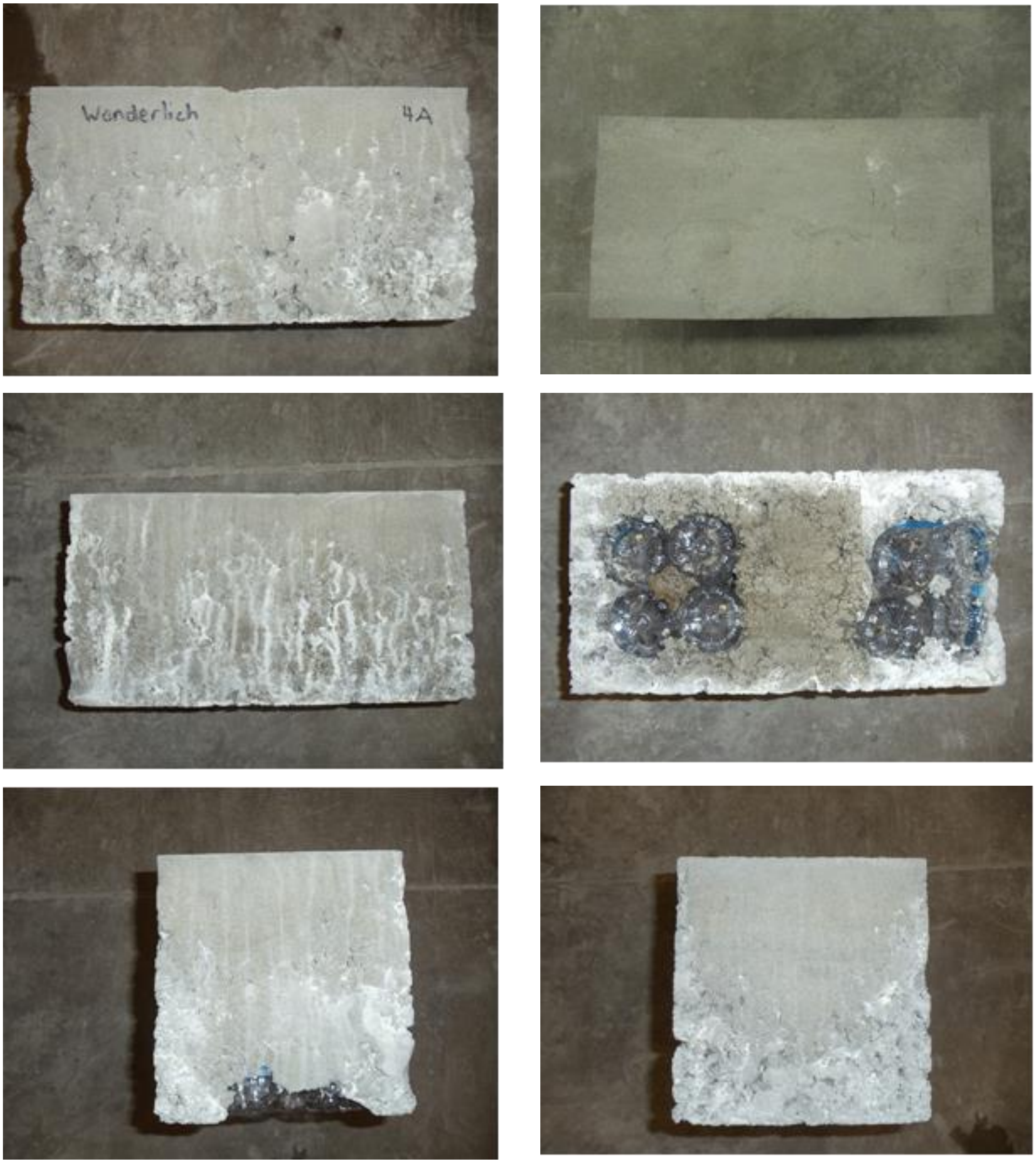

Figure A.10 Specimen 4A

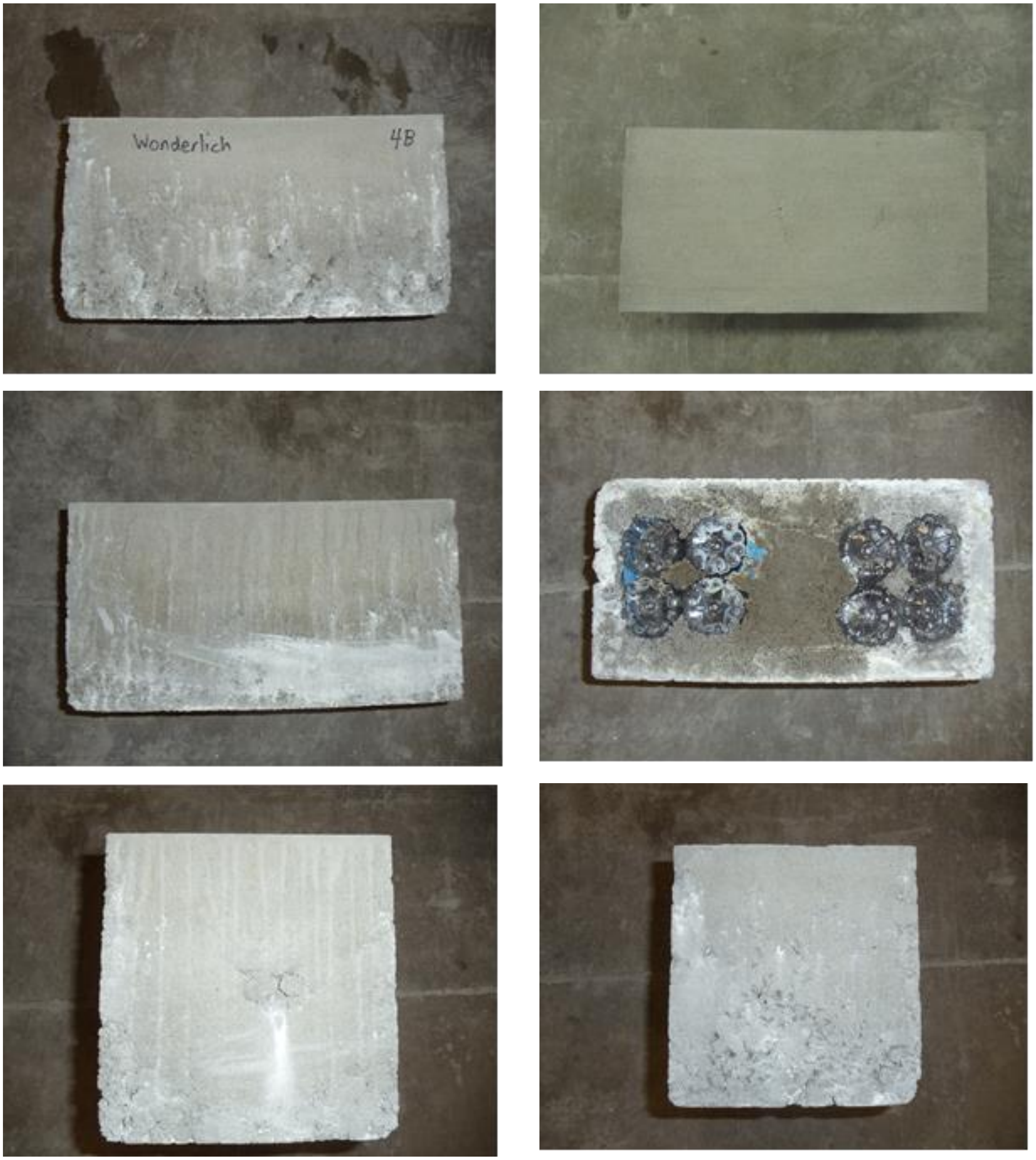

Figure A.11 Specimen 4B

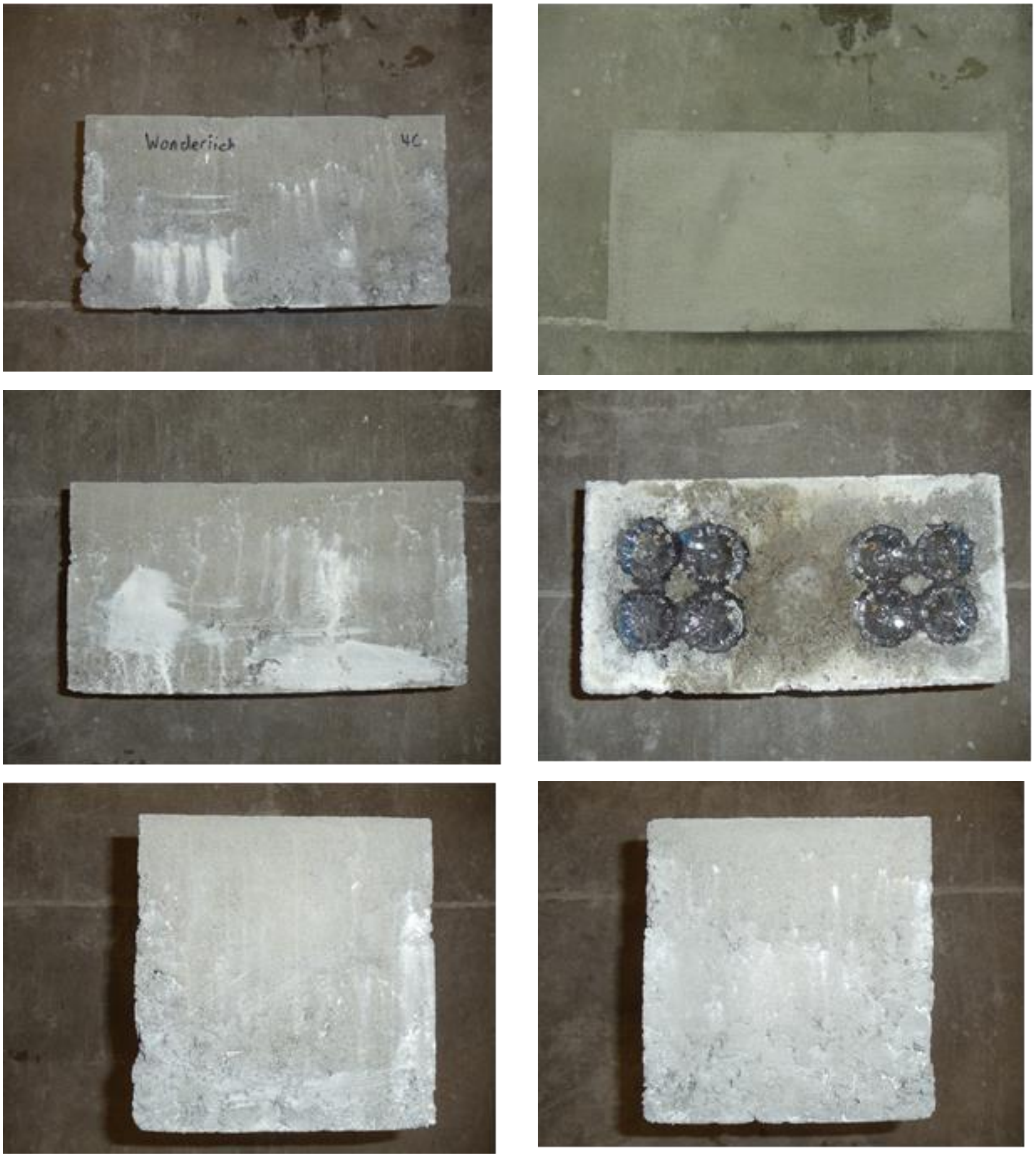

Figure A.12 Specimen 4C

Figure A.13 Specimen 5A

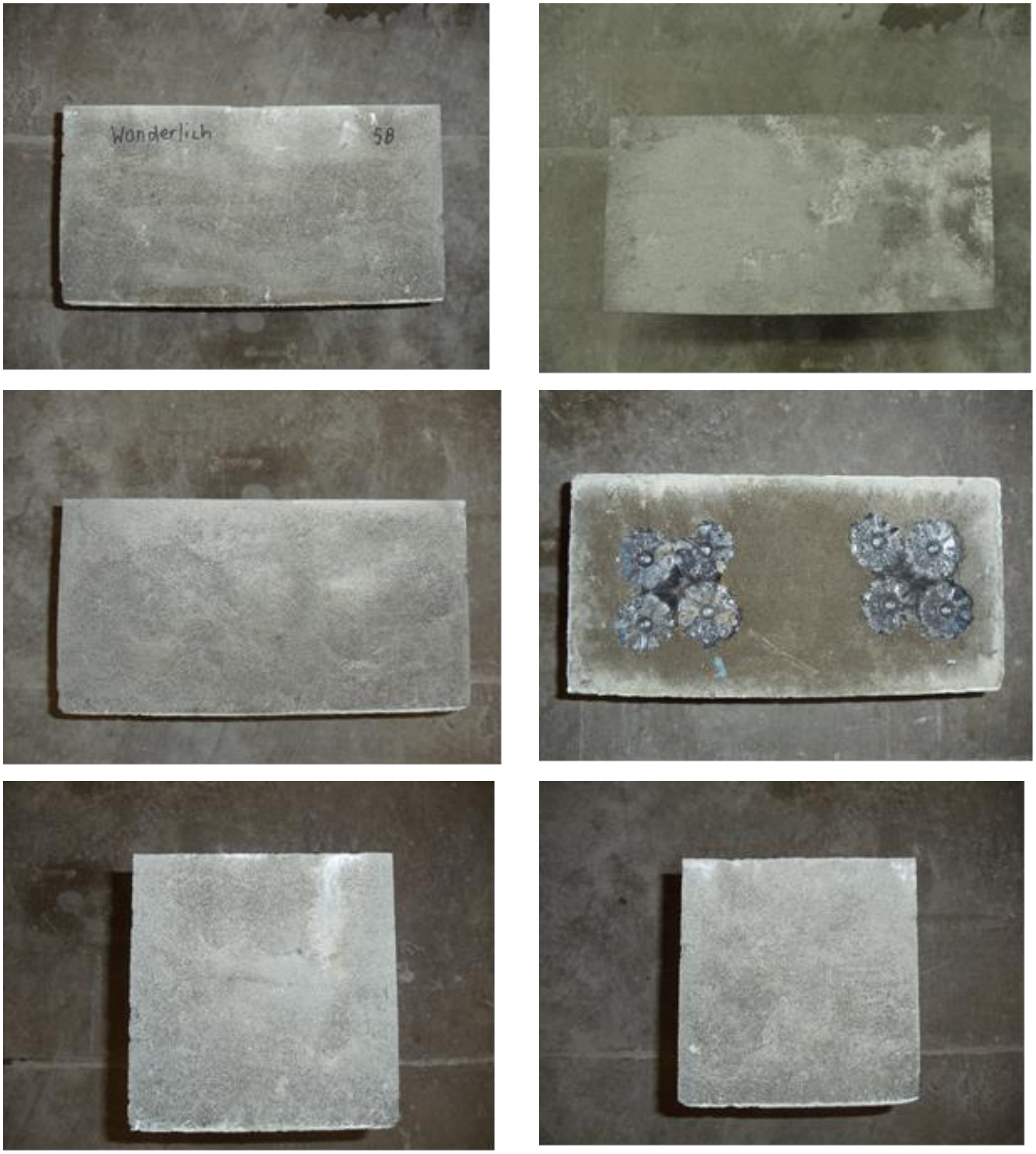

Figure A.14 Specimen 5B

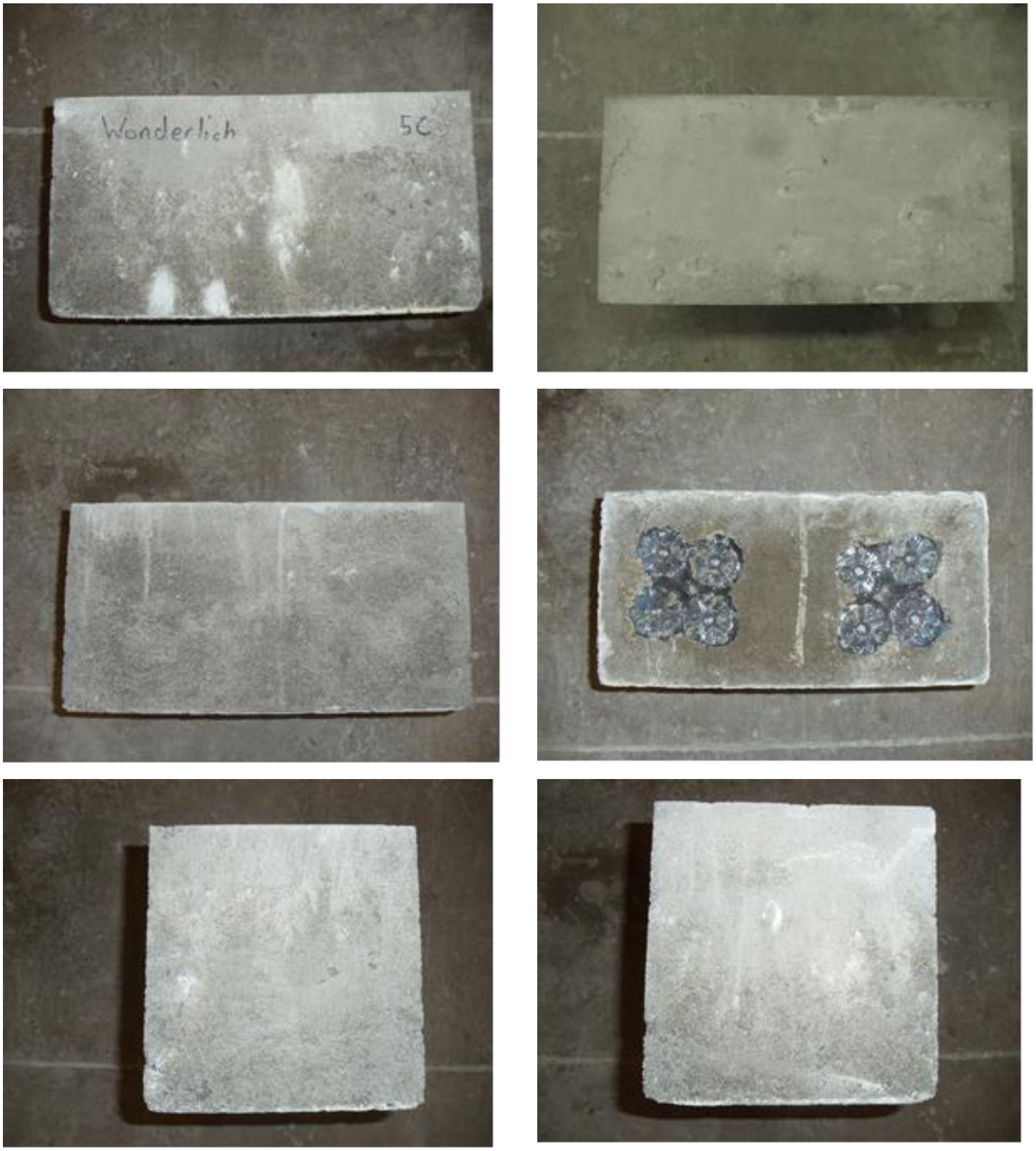

Figure A.15 Specimen 5C