Investigation of Natural Pozzolans:

Analyzing the Practicality of Natural Pozzolans as a Partial Substitute for Cement in Grout Production

A Senior Project
presented to
Architectural Engineering Faculty
California Polytechnic University, San Luis Obispo
Advised by Craig Baltimore
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1. Nomenclature

Bottom Ash: Powdery coal combustion residue that remains at the bottom of a furnace due to its relatively high density compared to fly ash.

Bunker Fuel: The type of fuel used on any ship. The fuel is classified under 3 grades: Bunker A, Bunker B and Bunker C. Bunker C or residual fuel oil bunker is most used in the shipping industry and is the type of fuel considered in this report.

Capping: A step in the grout compression testing procedure as mentioned in ASTM C1019 10.8. The step involves the putting on of a hydraulic cement plaster paste on the bottom and the top of each grout specimen that is then flattened by glass panels. This is done in order to achieve a flat smooth surface so that a uniform pressure is achieved during the loading of the grout specimen.

Coal Ash: A general term for the byproducts of coal combustion. Coal ash encompasses bottom ash and fly ash.

Cement: A substance made up of limestone clays and chalk that is used as a binding agent in grout and concrete mixes.

CMU: A block that is made up of concrete and used in the masonry industry standing for concrete masonry unit.

Curing: The process of keeping adequate moisture and temperature conditions for cement as it goes through the chemical process of hydration. Hydration is when the cement is mixed with water and starts to crystallize as it gradually soaks up the water.

Diesel #2 Fuel: The type of fuel commonly used in the trucking industry. In California Diesel #2 Fuel is the fuel used by all long-haul trucking companies and is the type of fuel considered in this report.

Grout: A mix of cement, aggregates and water used in the masonry industry to bind together CMUs or bricks. The material has a higher water content than concrete making grout better for filling gaps.

Harvested Fly Ash: Fly ash that is collected from storage facilities such as landfills and ash ponds.

Fly Ash: Powdery coal combustion residue that rises in the furnace due to its relatively low density compared to bottom ash. This material is currently used in the construction industry as a partial cement substitute in concrete and grout applications and is considered an artificial pozzolan.

Pozzolan: A siliceous material that gains binding properties similar to cement when in the presence of moisture and calcium hydroxide. There are natural pozzolans such as those that come from volcanic formations, and there are artificial pozzolans such as fly ash.

Slump Test: Measures the consistency of concrete immediately after it is mixed. It is performed to check the workability of a new batch of concrete, and therefore measures the ease of the concrete flow.

Ton: Unit of weight that is equivalent to 2,000 lbs. Also known as a U.S ton or short ton. Metric tons are slightly larger equaling 2204.6 lbs.

TEU: A Twenty Foot Equivalent Unit, A standard marine shipping container that measures 20 feet long, 8 feet wide, and 8.5 feet tall.

2. Purpose

This senior project aims to investigate whether natural pozzolans are more sustainable than fly ash and a sufficient substitute for cement in the production of grout. By following the intent of the ASTM (American Society of Testing and Materials) standards, a conclusion will be made to determine if natural pozzolans can contribute comparable strength in compression. The objective is to prove that natural pozzolans should be utilized in the production of grout rather than alternatives such as fly ash because it can provide similar strength while being more economical and more sustainable.

3. Introduction

Grout is a mixture utilized to fill the cavities of a CMU block in masonry construction. In grout, fly ash has traditionally been used to replace a portion of cement in a standard mix. However, it has been suggested that natural pozzolans may be a suitable substitute for this conventional fly ash.

The purpose of this investigation is to show that natural pozzolans are a reliable and sustainable choice in the construction industry. The research findings will demonstrate that natural pozzolans are more economical and sustainable than fly ash. The use of domestic natural pozzolans can reduce costs associated with potential future importing of fly ash from foreign countries and decrease pollution from the inefficient transportation methods used from that fly ash importation. Moreover, the use and production of natural pozzolans in the field can create more job opportunities for Americans, which can help with the current outsourcing of blue-collar jobs to foreign countries.

The grout produced in this experiment is a mixture of cement, water, lime, coarse and fine aggregates, and incremental amounts of natural pozzolan. The amounts used were proportioned in increments of 10 percent starting at 20 percent and ending at 50 percent of the total cement volume. These natural pozzolans used in testing were transported via truck from volcanic deposits in Nevada produced by Nevada Cement Company. The grout strength will be determined by conducting 12-day, 26-day, and 54-day compression tests per ASTM C1019 while varying the mix design with natural pozzolan quantities to determine the extent of any differences when compared to a control mix design with zero natural pozzolans.

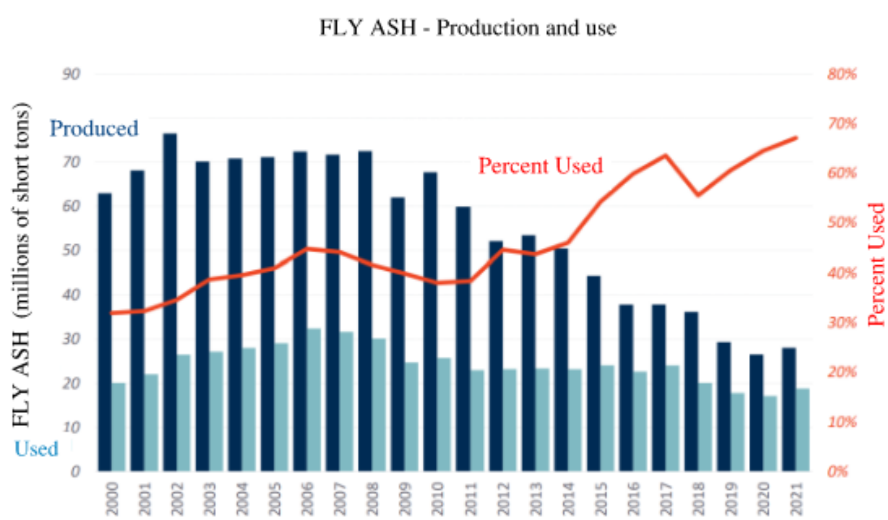
The strength of the material is critical for this study because it is a reliable indicator of grout quality. It is important to note that the compression tests in this study will follow the intent of ASTM C1019. The tests will not follow laboratory curing conditions as per ASTM C157 5.4.1 but rather will have "absorption conditions similar to those experienced by grout in the wall" per ASTM C1019 3.3. To obtain these conditions, the cells of CMU blocks will be filled with grout and left to cure. This approach aims to provide an accurate representation of real-world strength values due to the field curing conditions. The compression test results will indicate whether natural pozzolans are an adequate replacement for fly ash in the construction industry. If the results show a significant difference, the theory is not valid. Conversely, if the substitution proves successful, these findings could lead to a healthier and more affordable society.

4. Background

4.1 Fly Ash

Fly ash is used as a partial substitute for cement in the concrete and grout industry. As a partial cement substitute, fly ash has been marketed as sustainable in concrete construction since cement production consumes a lot of energy; however, fly ash may not be as sustainable as the industry has been led to believe. Sustainability according to the U.S General Services Administration seeks to, “reduce consumption of non-renewable resources, minimize waste, and create healthy, productive environments” (U.S General Services Administration 2023). Fly ash, while reducing the amount of waste and pollution that comes along with cement production, is trending towards becoming a non-renewable resource and is not a viable solution in the long run if consumption remains constant.

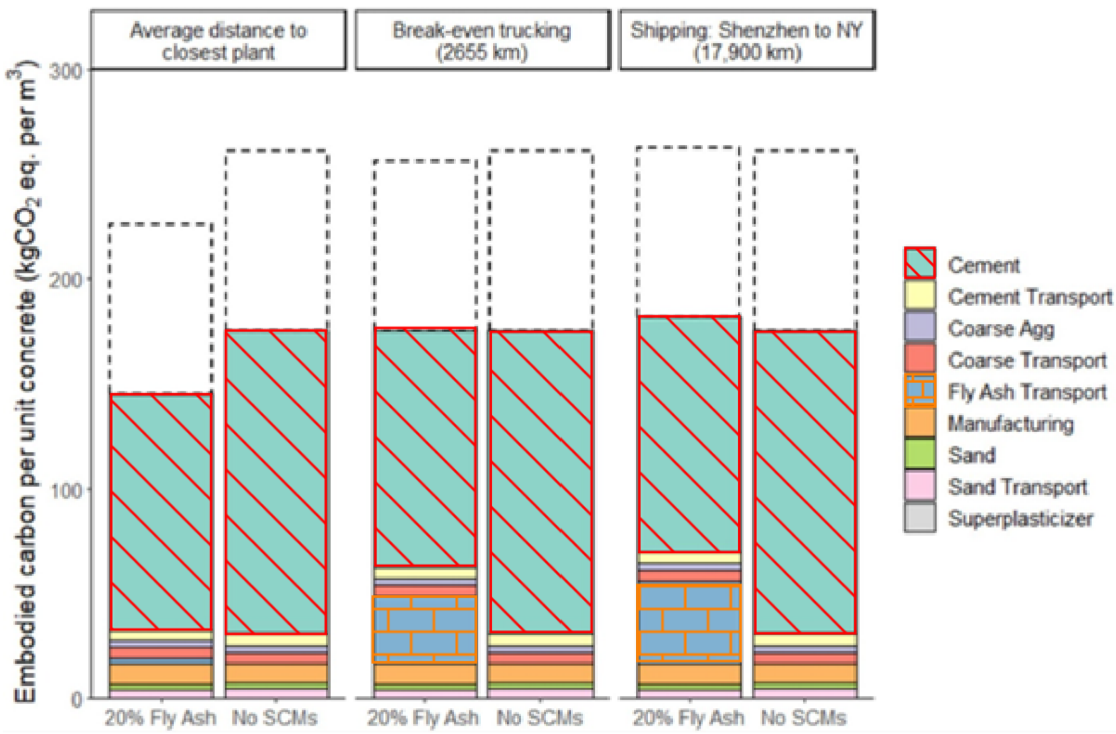
This trend as a non-renewable resource is occurring due in part to more and more coal plants being retired in the U.S. resulting in declining fly ash production. According to the American Coal Ash Association, power plants in the U.S. in 2017 produced 38 million tons of fly ash, while decreasing production to just 28 million tons in 2021 (Adams 2022). Fly ash recycling rates have been on the rise which to some extent counteracts the decreasing total production. In 2000 just around 32% of fly ash was used, while in 2021, a little over 67% of fly ash was used with around 64% of that recycled fly ash being used in concrete and grout applications in that year (Adams 2022). Increasing the percentage of recycled fly ash with decreasing production still results in lower total production. Due to this decreasing production, there has been an increase in effort and research on the use of fly ash that has been stored in landfills and lagoons, as well as the use of bottom ash (Hooton et al. 2021). The use of stored fly ash and bottom ash seems like a good solution for the time being since the U.S has hundreds of landfill sites stockpiled with coal ash according to the EPA (United States Environmental Protection Agency 2022). The problem with the use of stored fly ash and bottom ash is that it isn’t sustainable for the long term. Assuming the U.S isn’t producing coal ash or is producing at a very reduced rate in the future, the supply at these sites will eventually run out and fly ash will be considered a non-renewable resource.



<u>Figure 1: U.S Fly Ash Production and Use</u>

Cite: Adams, T. (2022). *Fly Ash - Production and Use*

To solve the fly ash renewability problem, importing fly ash from other countries into the U.S should be considered. The importing of fly ash is logical due to the increasing industrialization of the world. Industrialization will lead to increased coal ash production rates worldwide, particularly in developing countries. Currently the U.S. imports a portion of its fly ash from Turkey, India and South Korea as well as from various other countries (Volza LLC 2023). The problem with importing fly ash into the U.S from other countries is that the importation causes lots of pollution and carbon emissions through the transportation of the fly ash via freighters. One study from the University of Colorado Boulder actually found that shipping fly ash over great distances (from Asia to the U.S) can eliminate any environmental benefits fly ash has and can actually worsen the material's environmental impact (DeRousseau et al. 2020). Due to negative effects that come from importing fly ash, this report will consider natural pozzolans produced domestically as a sustainable solution to replace fly ash in the construction industry.



<u>Figure 2: Embodied Carbon per Transportation Method with and without Fly Ash</u>
Cite: DeRousseau, M.A. et al (2020). *Comparison of embodied carbon for different transportation scenarios and fly ash replacements*

4.2 Bunker Fuel

As previously mentioned, fly ash importation has adverse effects on the environment due to pollution associated with transportation. Fly ash is transported aboard long-haul shipping freighters. According to The Geography of Transport Systems, the average shipping freighter is classified as a bulk vessel also known as a container vessel. These ships travel at a normal cruising speed of 24 knots (28 mph) and at a streaming speed of around 19 knots (22 mph) (Rodrigue 2023). These values are taken as the average speed when considering ship size, shape, and speed range; it is not a true representation of every possible ship in use today. One of the biggest environmental hazards of shipping is the consumption and storage of bunker fuel oil. Bunker fuel is residual fuel oil of high viscosity and is most commonly used in ocean travel. The average ship used in this transportation process uses about 225 metric tons per day of bunker fuel at cruising speed (Rodrigue 2023). This equates to 9.38 metric tons per hour of bunker fuel used. One metric ton is equal to 2,204.6 lbs. With bunker fuel having a density of 50 pcf and knowing there are 0.1336 cu ft/gal, it is given that one metric ton is equivalent to 330 gallons of fuel. When examining 9.38 metric tons per hour it is also safe to use 3,096 gallons per hour. This is a large quantity of fuel burned in a very rapid frame of time and is especially bad when considering the fuel type used in this process is bunker fuel. At this rate of consumption, there will be a large amount of fuel burned for long distance transportation. Taking for example a ship traveling from South Korea to California, the number of gallons used can be calculated. The average shipping distance from South Korea to California is 5,050 miles. This is an average time of 180.36h or 7.5 days traveling at 24 knots (28 mph). Given that amount of time, 560,000 gallons of fuel is consumed with 1,120,000 gallons being consumed round trip.

4.3 Bunker Fuel Ship VS. #2 Diesel Truck

Once the quantity of fuel burned in a shipping route is known, it is vital to compare with the alternative shipping methods used in the transportation of natural pozzolans. A ship that burns 225 metric tons of fuel per day can hold 8,000 Twenty Equipment Units (TEUs). This is equivalent to 8,000 shipping containers that are 20 feet long x 8.5 feet high x 8 feet in width. The fly ash shipped in these units has a bulk density of 30 lb/cu ft (Brabender 2023) and the average container is 1360 cu ft. Therefore, each container can fit 40,800 lbs of fly ash. The relative size of this quantity of material will fill the volume of the container, which has a limit of 52,900 lbs per container. This means each shipment by boat can yield 326,400,000 lbs of fly ash in all 8,000 shipping containers. This total weight of fly ash transported can be compared to the weight of natural pozzolans shipped in a standard long-haul truck. According to Transwest, the average long-haul truck has a trailer size of 53’x14’x8.5’. This gives a volume of 6307 cu ft per truck trailer (Team 2023). The U.S. Department of Transportation limits the capacity of gross weight to 80,000 lbs for a tri-axle trailer, and the average truck unloaded is 15,000 lbs (Team 2023). This gives the max cargo load to be 65,000 lbs. Utilizing a tri axle trailer over a typical double or single axle trailer allows for a heavier load to be transported while still abiding by department regulations. Domestically sourced natural pozzolans have a density of 48 lb/cft (CRMinerals 2023), and using the 65,000 lbs trailer capacity of pozzolans, the volume needed is 1354 cu ft which can fit in the trailer volume. This is less than the maximum capacity of the trailer and therefore can be used further in the analysis. When comparing the methods of shipment and the quantity of trucks required to achieve the same amount of shipped product, it would take 5000 trucks to equal 1 bunker vessel on a purely capacity oriented analysis. For a truck, the distance from Nevada Cement Company to San Luis Obispo California is 450 miles. The average semi-truck gas mileage is about 7.5 miles per gallon which means about 60 gallons of diesel #2 fuel would be consumed per truck. Given 5000 trucks to transport the same amount of weight as 1 bulk vessel, 300,000 gallons of diesel #2 would be used. 300,000 gallons of diesel #2 is well below the 560,000-gallon one way port to port consumption of bunker fuel. It should also be noted that the ship transporting fly ash would also require trucking fuel to get to San Luis Obispo which would add an additional 140,000 gallons of diesel #2 if transported from Long Beach. This comparison of total gallons used demonstrates that the trucking of natural pozzolans is a comparable substitute to shipping fly ash by use of bulk vessels.

Not only is trucking more efficient in terms of the quantity of gallons of fuel used, but it is far better in the quality of the fuel being burned off. Trucks use diesel #2 fuel which according to Kendrick Oil is defined as a "chemical compound that holds the highest amount of energy components and lubricant properties in one mixture and offers the best fuel performance available on the market today" (SEO 2018). This diesel type also doesn't require the same depth of refinement as other grades of diesel fuel. On the other hand, the storage and burning of bunker fuel causes many pollutants to be released into the environment. These pollutants are causing and have caused many environmental impacts that are being felt around the world. One of the biggest pollutants and byproducts of bunker fuel is sulfur. According to the U.S. Energy Information Administration, for the marine shipping industry, there are sulfur limits set in place to help mitigate these effects (Ricker 2023). While this is true, there are still better and more environmentally friendly ways of sourcing fly ash alternatives such as natural pozzolans. A ship uses 225 metric tons of bunker fuel per day at cruising speeds. For 7.5 days it is expected that total fuel used is upwards of 1688 metric tons. This is in contrast with the still harmful but more regulated trucking industry. The trucks used in shipping do not produce sulfur, but instead create carbon dioxide. For trucks, diesel #2 fuel consumptions in the United States have resulted in the emission of carbon dioxide. Carbon dioxide is a common greenhouse gas that in large quantities is still very harmful to the environment. Fortunately, in the U.S. there are trucking regulations that only permit a certain level of carbon dioxide to be omitted into the atmosphere. When looking at the world, the United States is on the cutting edge of pollution regulations. Many such regulations centered around the trucking industry. Trucking pollution and use of natural pozzolans in the U.S. is drastically more environmentally stable than that of sulfur pollution produced by globally sourced shipping.

5. Experiment

This section will cover in detail the information necessary to carry out the grout compression test used to justify the utilization of natural pozzolan in the production of grout, as specified in ASTM C1019. This will include materials, the location of the experiment, and an explanation of the following processes with supplemental images of:

- Mix procedure
- Slump test
- Grout curing
- Grout sample cutting
- Capping and compression testing

5.1 Materials

The determination of the grout mix design followed the intent of ASTM C476 by portioning out components based on volume within the provided range for conventional grout in Table 5.3.1.1. Adjustments to water volume were made to obtain a soupy mix consistency and recorded in Table 5.3.1-4. Components used in the mix design are as follows:

- Type II/V Portland Cement (PC) from Cal Portland
- Domestic natural pozzolans from Nevada Cement Company
- High calcium hydrated lime from Western Lime
- Sand (fine aggregate)
- Gravel (coarse aggregate)
- Hose water

Equipment used to mix were:

- Digital scale with accuracy to the hundredths ± 0.02
- Electric drum mixer with 5 cubic foot capacity – loaded to 3 cubic foot maximum
- Wheelbarrow
- Metal hoe
- Gallon buckets
- 6 in. x 12 in. plastic cylinder molds

Equipment used to conduct the slump test as per ASTM C143 include:

- Slump cone mold
- Metal tray
- Metal rod
- Tape measurer

Equipment used in the pouring and curing processes are:

- 40 double corner CMU blocks (80 total cells)
- Wheelbarrow
- Metal scoop
- Metal rod
- Moisture controlled room with level surface
- Wetted paper towels

Equipment used to cut grouted samples include:

- Concrete wet saw
- Cured CMU blocks (6 in)

Equipment used in the capping and testing procedures consist of:

- Plaster
- Pledge® enhancing polish – lemon scent
- Glass plates
- Metal weights
- CM-5000 Series Compression Testing Machine

5.2 Location

All procedures took place on the campus of California Polytechnic State University, San Luis Obispo. Grout mixing, cutting, and slump testing were performed in the CAED Concrete Yard, while the curing and compression strength testing of the grout samples took place in Engineering West Building 21, Room 17.

5.3 Experimental Procedure

This section will cover the procedure leading up to the compression tests of the grouted samples. Compression tests were originally planned after 12, 26, and 54 days of curing. Due to strength discrepancies found during the 12-Day Test, the mixes for 0%, 20%, and 30% natural pozzolan substitution were re-mixed using a wheelbarrow and remeasured proportions. It was expected that these samples contained more sand and less cement than designed for due to their low strength, flaky texture, and tan color as pictured in Figure 14 in Section 5.3.5 below. These new mixes underwent compression testing after 14 and 28 days of curing. Though new batches of mix were produced, the original mixes were tested throughout the experiment for additional data.

5.3.1 Mixing

Prior to mixing, calculations were completed to portion out the proper mix design. The theoretical proportions were within the range ASTM C476 provides for conventional grout mix proportions by volume in Table 5.3.1-1. The actual mix design was slightly modified to achieve the desired consistency. Each of theoretical and actual mix designs are located below in Tables 5.3.1-2 through 5.3.1-5 below. Grout components were mixed using two methods: the mechanical concrete mixer (Figure 3) for the original mix and a wheelbarrow (Figure 4) for the new mix. The wheelbarrow method was used to correct unexpected low strength results most likely due to non-uniform mixes by creating an evenly distributed mix and to avoid clumping from the mechanical concrete mixer. Dry components were added first and mixed for five minutes to ensure even distribution. This included sand, gravel, Portland cement, hydrated lime, and natural pozzolans (if required by specific mix design). Frequently a rod was used to get rid of clumps. Next, water was added in intervals to prevent the mixture from forming clumps. Following the combination of each component, the mixer was operated for an additional five minutes to ensure the right consistency; qualitatively soupy.

Table 5.3.1-1 ASTM C476 Conventional mix proportions by volume

TABLE 1 Conventional Grout Proportions by Volume

Type	Parts by Volume of Cement[A]	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

Figure 3. Mixing with electric concrete mixer

Figure 4. Mixing in wheelbarrow

Table 5.3.1-2 Theoretical mix proportions by volume

Theoretical Prism Test Mix Proportions by Volume (in³)							
Sample ID	Part by Volume of PC	Part by Volume of Natural Pozzolans	Parts by Volume of Hydrated Lime	Aggregate Measure in a Damp Loose Condition		Dry Volume Total	Water Volume Total
				Fine	Coarse		
PC	540	0	40.5	1350	810	2740.5	585
NP (20%)	432	108	40.5	1350	810	2740.5	585
NP (30%)	378	162	40.5	1350	810	2740.5	585
NP (40%)	324	216	40.5	1350	810	2740.5	585
NP (50%)	270	270	40.5	1350	810	2740.5	585

Table 5.3.1-3 Theoretical mix proportions by weight

Theoretical Prism Test Mix Proportions by Weight (lb)							
Sample ID	Part by Weight of PC	Part by Weight of Natural Pozzolans	Parts by Weight of Hydrated Lime	Aggregate Measure in a Damp Loose Condition		Dry Weight Total	Water Weight Total
				Fine	Coarse		
PC	23.1	0	0.9375	59.1	41.31	124.45	15.9
NP (20%)	19.5	3	0.9375	58.2	39.6	121.24	15.9
NP (30%)	16.2	4.8	0.9375	58.5	39.3	119.74	15.9
NP (40%)	13.8	5.4	0.9375	58.8	41.1	120.04	15.9
NP (50%)	11.1	7.8	0.9375	58.2	39.9	117.94	15.9

Table 5.3.1-4 Actual mix proportions by volume (Original Mix)

Actual Original Prism Test Mix Proportions by Volume (in³)							
Sample ID	Part by Volume of PC	Part by Volume of Natural Pozzolans	Parts by Volume of Hydrated Lime	Aggregate Measure in a Damp Loose Condition		Dry Volume Total	Water Volume Total
				Fine	Coarse		
PC	508.9	0	50.9	1324.7	720	2604.5	575
NP (20%)	407.12	101.78	50.9	1324.7	720	2604.5	575
NP (30%)	356.23	152.67	50.9	1324.7	720	2604.5	575
NP (40%)	305.34	203.56	50.9	1324.7	720	2604.5	575
NP (50%)	254.45	254.45	50.9	1324.7	720	2604.5	575

Table 5.3.1-5. Actual mix proportions by weight (New Mix)

Actual Re-Mix Prism Test Mix Proportions by Weight (in³)							
Sample ID	Part by Weight of PC	Part by Weight of Natural Pozzolans	Parts by Weight of Hydrated Lime	Aggregate Measure in a Damp Loose Condition		Dry Weight Total	Water Weight Total
				Fine	Coarse		
PC	22.18	0	0.83	63.97	41.68	128.66	17.38
NP (20%)	17.75	4.44	0.88	63.47	41.68	128.22	14.86
NP (30%)	15.53	6.65	0.78	63.47	41.68	128.11	14.54

5.3.2 Slump Test

The concrete slump test was conducted following the intent of ASTM C143 as explained in this section. Once the desired consistency was achieved, a slump cone mold was positioned on top of a flat metal tray with feet planted on the sides of the cone to hold it firmly in place. This setup is displayed below in Figure 6. A portion of the mix was then scooped into the cone in 3 layers (approx. 1/3 cone volume per layer), each time being rodded down 25 times uniformly across the entire cross section to ensure proper consolidation. Once the top layer was filled and rodded, the rod was used to level off the top before the cone was removed directly upwards in one motion. Measurements were taken immediately from the top of the mold to the peak of the slump and required to be within 8-11 inches as per ASTM C476 4.2.1. This procedure is pictured in Figure 5. Slumps were recorded to the nearest ¼ in. and are displayed below in Tables 5.3.2-1 and 5.3.2-2.

Figure 5. Slump measurement

Figure 6. Rodding grout with correct foot placement

Table 5.3.2-1 Slump test for original mix

Sample Slump Test Results of Original Mix	
Sample ID	Slump (in)
PC	8.5
NP (20%)	10.75
NP (30%)	9
NP (40%)	10.75
NP (50%)	10.5

Table 5.3.2-2 Slump test for re-mix

Sample Slump Test Results of Re-Mix	
Sample ID	Slump (in)
PC	9.5
NP (20%)	9.5
NP (30%)	9.25

5.3.3 Pouring and Curing

Once slump requirements were met, grout was poured into CMU cells and rodded, then left to cure. The labeling convention consisted of dots representing the percentage of natural pozzolan substitution (e.g., two dots for 20% substitution). Figure 7 below provides a visual of this naming scheme. Grout curing followed the intent of ASTM C1019, which involved covering the surface with a damp cloth and storing them in temperatures ranging from 60°F to 80°F. As shown in Figure 8, the CMUs were stored in a controlled environment in Engineering West Building 21, Room 17.

Figure 7. CMU blocks with labels and empty cell

Figure 8. CMU blocks after filling cells and covering with damp cloth

5.3.4 Cutting

After meeting the desired curing time (e.g., 12 days for the 12-Day Test), the CMUs were cut into samples using a concrete wet saw as displayed in Figure 9. To ensure accurate strength values, three samples were cut for each level of pozzolan substitution on each test day. The blocks were cut on all six sides to meet the desired dimensions as well as create a flat surface for testing. This also allowed for the walls of the CMU block to be removed such that when testing, the only material was the grout itself. To remain in accordance with ASTM C1019-20 6.1.2 and 6.1.3, the specified dimensions were cut to a width between 3.0 and 3.75 inches and a height between 1.75 and 2 times the average width of each sample. In this experiment, 1.85 was used as the multiplier. Dimensions were recorded to the nearest 1/16 inch and taken at mid-width and mid-height of each side surface as shown in Figure 10. Once each block was cut, the saw and surrounding area were cleaned with a water hose and stored away. Samples were labeled using the same naming convention and assigned numbers 1-3 to organize the recorded strengths.

Figure 9. Wet saw used to cut grout samples out of CMU cells

Figure 10. Sample height measured at mid-height

5.3.5 Capping and Testing

After cutting the samples, hydraulic cement plaster powder and water were mixed in a tin metal tray. Before plaster was applied, all glass plates were sprayed with lemon scented non-stick enhancing polish to prevent sticking for easy removal. Grout samples were firmly pressed into the plaster as displayed in Figure 11, then topped with plaster and another glass plate with a weight shown in Figure 12. Once left to dry for approximately 30 minutes, the plastered samples were separated from the glass plates with a twisting motion and compressed in the testing machine one at a time.

In the CM-5000 Series Compression Testing Machine shown in Figure 13, a stack of metal blocks was used as a platform to decrease the gap between the top of the samples and the head of the machine. Compression load was applied until the sample failed, which was represented by a drop in applied loading on the screen. Figure 15 below displays a visual representation of this failure. Once this occurred, the final loading was recorded and used to calculate the compression strength of each sample. This was done by dividing the force by the cross-sectional area and is measured in PSI (Pounds per square inch). Following each test, the samples were placed in a wheelbarrow shown in Figure 16 and disposed of in a concrete-only waste bin. The machine was then cleaned in preparation for the next test to prevent any bias.

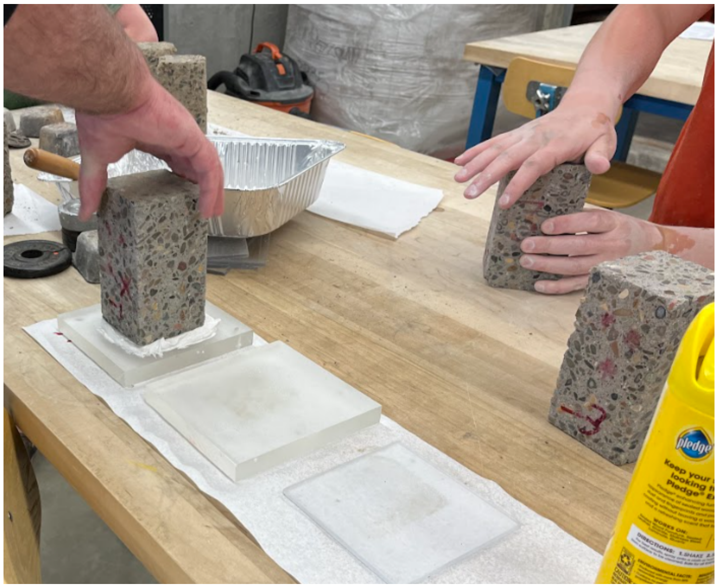


Figure 11. Capping bottom end of samples for testing

Figure 12. Plaster drying process

Figure 13. CM-5000 Compression Testing Machine

Figure 14. Tan coloring of sample containing excessive sand

Figure 15. Sample failure following compression test

Figure 16. Samples in wheelbarrow prior to being disposed of

6. Results

This section provides results of grout prism testing on days 12, 26, and 54 for the original mix and days 14 and 28 for the re-mix. For information on the testing procedure, refer to section 5.3.5.

6.1 Specimen Recorded Dimensions

As described in section 5.3.4, specified dimensions were cut to a width between 3.0 and 3.75 inches and a height between 1.75 and 2 times the average width of each sample in accordance with ASTM C1019-20 6.1.2 and 6.1.3. Dimensions were taken at mid-width and mid-height of each side surface and were recorded to the nearest 1/16 inch as displayed below in Table 6.1-1 and 6.1-2.

Table 6.1-1 Original Mix Specimen Dimensions

Original Mix Design										
Percent Pozzolan	Dimension	12 Day Test			26 Day Test			54 Day Test		
		Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3
0%	Width [In]	3 3/16	3 1/16	3 1/16	3 3/16	3 1/8	3 3/16	3 1/4	3 5/16	3 5/16
		3 1/4	3 1/8	3	3 1/8	3 3/16	3 3/16	3 1/4	3 3/16	3 1/4
		3 1/8	3 3/16	3 1/8	3 3/16	3 3/16	3 1/8	3 1/4	3 3/8	3 5/16
		3 1/4	3 1/8	3 1/16	3 1/8	3 3/16	3 3/16	3 5/16	3 3/16	3 1/4
	Height [In]	5 3/4	5 3/4	5 13/16	6	5 7/8	5 13/16	6	5 15/16	6
		5 11/16	5 3/4	5 13/16	6	5 13/16	5 13/16	6	5 15/16	6
		5 11/16	5 3/4	5 13/16	6	5 7/8	5 13/16	5 15/16	5 15/16	6
		5 3/4	5 3/4	5 13/16	6	5 7/8	5 7/8	5 15/16	5 15/16	6
20%	Width [In]	3 1/8	3	3 1/8	3 3/16	3 3/16	3 1/16	3 3/16	3 5/16	3 3/8
		3	3 1/8	3 5/16	3 3/16	3 3/16	3 1/8	3 5/16	3 1/4	3 3/16
		3 1/8	3 1/16	3 1/8	3 1/4	3 3/16	3 1/8	3 1/4	3 1/4	3 3/8
		3 1/16	3 1/8	3 5/16	3 1/8	3 3/16	3 3/16	3 5/16	3 1/4	3 3/16
	Height [In]	5 5/8	5 3/4	5 3/4	6	5 13/16	5 3/4	5 15/16	5 7/8	5 3/4
		5 11/16	5 3/4	5 3/4	6	5 7/8	5 13/16	5 7/8	5 7/8	5 13/16
		5 11/16	5 13/16	5 3/4	5 15/16	5 7/8	5 3/4	5 7/8	5 15/16	5 13/16
		5 5/8	5 3/4	5 3/4	5 15/16	5 7/8	5 3/4	5 15/16	5 15/16	5 3/4
30%	Width [In]	3 3/16	3 1/8	3 1/8	3 3/16	3 1/4	3 1/4	3 3/16	3 3/16	3 1/4
		3 3/16	3 1/4	3 3/16	3 1/4	3 5/16	3 1/4	3 1/4	3 1/4	3 5/16
		3 3/16	3 3/16	3 1/8	3 1/4	3 1/4	3 1/4	3 3/16	3 3/16	3 1/4
		3 3/16	3 1/4	3 1/4	3 3/16	3 5/16	3 1/4	3 5/16	3 5/16	3 5/16
	Height [In]	5 7/8	5 15/16	7 1/2	6 1/16	5 15/16	5 7/8	6 1/16	6	6 1/16
		5 7/8	5 15/16	5 7/8	6 1/16	5 15/16	5 7/8	6 1/16	6	6
		5 7/8	5 7/8	5 7/8	6 1/8	5 15/16	5 13/16	6 1/16	6	6
		5 13/16	5 15/16	5 15/16	6 1/16	5 15/16	5 7/8	6 1/16	6	6
40%	Width [In]	3 1/16	3 5/16	3 3/16	3 5/16	3 3/16	3 1/4	3 1/4	3 5/16	3 1/4
		3 1/4	3 1/4	3 1/4	3 3/16	3 1/4	3 1/4	3 5/16	3 1/4	3 3/8
		3 1/8	3 5/16	3 3/16	3 5/16	3 1/4	3 3/16	3 1/4	3 1/4	3 5/16
		3 1/4	3 1/4	3 3/16	3 1/4	3 3/16	3 1/4	3 1/4	3 5/16	3 3/8
	Height [In]	5 15/16	6 1/16	6	6	5 7/8	5 7/8	6	6	6 1/16
		6	6 1/16	6	6	5 15/16	5 15/16	6	6	6 1/16
		6	6 1/16	6	6	5 15/16	5 15/16	6	6	6 1/16
		5 15/16	6 1/16	6	6	5 7/8	5 7/8	6	6	6 1/16
50%	Width [In]	3 1/8	3 3/16	3 1/4	3 3/16	3 1/16	3 1/4	3 3/8	3 3/8	3 5/16
		3 1/8	3 3/16	3 1/8	3 1/4	3 3/16	3 1/4	3 5/16	3 5/16	3 1/4
		3 1/8	3 3/16	3 1/4	3 3/16	3 1/8	3 1/4	3 5/16	3 5/16	3 5/16
		3 3/16	3 1/4	3 1/8	3 1/4	3 3/16	3 1/4	3 5/16	3 3/8	3 5/16
	Height [In]	5 7/8	5 3/4	5 3/4	5 7/8	5 5/8	5 7/8	5 15/16	6 1/8	6 1/8
		5 3/4	5 3/4	5 11/16	5 7/8	5 5/8	5 7/8	6	6 1/8	6 1/16
		5 3/4	5 3/4	5 11/16	5 7/8	5 5/8	5 15/16	6	6 1/8	6 1/16
		5 3/4	5 3/4	5 3/4	5 7/8	5 5/8	5 7/8	6	6 1/16	6 1/16

Table 6.1-2 Re-Mix Specimen Dimensions

New Mix Design							
Percent Pozzolan	Dimension	14 Day Test			28 Day Test		
		Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3
0%	***Width [In]***	3 5/16	3 3/16	3 3/16	3 1/4	3 5/16	3 5/16
		3 3/16	3 5/16	3 1/4	3 5/16	3 1/4	3 5/16
		3 1/4	3 3/16	3 3/16	3 1/4	3 5/16	3 5/16
		3 3/16	3 5/16	3 1/4	3 5/16	3 1/4	3 1/4
	Height [In]	5 15/16	5 15/16	6	6 1/16	6	5 13/16
		6	5 15/16	6	6 1/16	6	5 7/8
		6	5 15/16	6	6 1/16	6 1/16	5 7/8
		6	6	6	6 1/16	6 1/16	5 13/16
20%	***Width [In]***	3 5/16	3 5/16	3 3/8	3 1/4	3 1/8	3 1/4
		3 1/4	3 1/4	3 3/8	3 5/16	3 3/16	3 1/8
		3 1/4	3 5/16	3 1/4	3 3/16	3 3/16	3 1/8
		3 3/16	3 1/4	3 3/8	3 5/16	3 5/16	3 1/16
	Height [In]	5 15/16	6	6	5 15/16	5 13/16	5 13/16
		5 15/16	6	6	5 15/16	5 13/16	5 13/16
		5 15/16	6	6	5 15/16	5 13/16	5 13/16
		5 15/16	6	6	6	5 13/16	5 13/16
30%	***Width [In]***	3 5/16	3 1/8	3 1/4	3 1/4	3 1/4	3 3/8
		3 3/16	3 1/4	3 1/4	3 3/8	3 1/4	3 7/16
		3 1/4	3 1/8	3 1/4	3 1/4	3 5/16	3 5/16
		3 3/16	3 1/4	3 5/16	3 3/8	3 5/16	3 3/8
	Height [In]	6 1/16	5 3/4	6 1/8	6	6	6
		6 1/16	5 13/16	6 1/8	6	6 1/16	5 15/16
		6 1/16	5 13/16	6 1/16	6 1/16	6	6
		6 1/8	5 13/16	6 1/8	6	6	6

6.2 Compression Results

Once the dimensions were recorded, the specimens were then subject to a compressive force by a CM-5000 Series Compression Testing Machine. The maximum load prior to failure was documented for each sample in the field book. The cross-sectional area was calculated by multiplying the average of the sample widths on each side. By dividing the recorded load by these cross-sectional areas, the compression strength was determined per sample. The compressive strengths of all samples are tabulated in Table 6.2-1 and 6.2-2, then averaged as displayed in Table 6.2-3.

Table 6.2-1 Test Results of Original Mix

Original Mix Design										
Percent Pozzolan Substitution	Data Recorded	12 Day Test			26 Day Test			54 Day Test		
		Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3
0%	Force [lb]	4,970	5,440	4,960	8,570	7,050	6,890	7,060	8,910	8,640
	Strength [PSI]	485	557	529	860	701	685	662	836	803
20%	Force [lb]	1,080	1,340	1,270	1,910	1,810	2,000	2,940	3,220	3,340
	Strength [PSI]	114	141	123	188	178	205	276	302	310
30%	Force [lb]	9,450	8,810	10,480	15,730	14,850	10,970	18,630	19,560	20,990
	Strength [PSI]	930	859	1,042	1,518	1,379	1,039	1,781	1,870	1,950
40%	Force [lb]	6,310	5,450	5,380	8,610	7,470	7,120	10,790	9,390	11,690
	Strength [PSI]	628	506	524	808	721	681	1,012	872	1,056
50%	Force [lb]	5,210	4,690	5,160	6,170	6,800	8,130	12,210	13,370	12,980
	Strength [PSI]	958	859	1,032	1,518	1,506	1,039	1,682	1,749	1,931

Table 6.2-2 Test Results of Re-Mix

Re-Mix Design							
Percent Pozzolan Substitution	Data Recorded	14 Day Test			28 Day Test		
		Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3
0%	Force [lb]	20,650	23,330	20,510	12,740	31,380	22,060
	Strength [PSI]	1,974	2,210	1,980	1,183	2,915	2,030
20%	Force [lb]	16,350	17,790	19,090	19,240	21,590	17,930
	Strength [PSI]	1,548	1,652	1,708	1,805	2,105	1,818
30%	Force [lb]	15,850	17,170	18,140	24,610	23,290	26,250
	Strength [PSI]	1,515	1,691	1,701	2,244	2,163	2,305

Table 6.2-3 Average Compressive Strength of Original Mix and Re-Mix

Average Strength						
Percent Pozzolan Substitution	Data Recorded	Re-Mix Design		Original Mix Design		
		14 Day Test	28 Day Test	12 Day Test	26 Day Test	54 Day Test
0%	Strength [PSI]	2,055	2,473	523	749	767
20%	Strength [PSI]	1,636	1,909	126	190	296
30%	Strength [PSI]	1,636	2,237	944	1,312	1,867
40%	Strength [PSI]	N/A	N/A	553	736	980
50%	Strength [PSI]	N/A	N/A	950	1,354	1,788

After the 12-day test, it was clear that the 20% pozzolan sample in the original mix had a noticeably lower strength than expected and compared to the 0%, 30%, 40% and 50% mix. With these results along with the observation of a tan color and sandy texture of the sample shown in Figure 14, the 20% samples were deemed to have a lower cement proportion than the design mix called for. The inconsistency in the mix composition caused the lower strength. The 0% also yielded strengths lower than expected due to the partial segregation of cement from the samples as clumps formed in the electric drum mixer, therefore the 0%, 20% and 30% mixtures were re-mixed. This re-mixing process consisted of the same mix ratios as before, but this time the quantities were hand mixed by use of a wheelbarrow. Since the 30% mix performed as expected, it was used as a reference to connect the original mix to the re-mix by comparing the similar strengths.

As expected, the average strength of all samples increased as the cement was given a longer period to cure. At 54 days, the 30% yielded an average strength of 1,867 psi, the 40% yielded an average strength of 980 psi, and the 50% yielded an average strength of 1,787 psi. With the unexpectedly low values for the 0% mix, a conclusion could not be made regarding the difference in strength when substituting natural pozzolans compared to the control sample with 0% pozzolan.

Due to time restrictions, a 56-day test was not conducted for the re-mix. The 0% and 20% natural pozzolan re-mixes produced results that aligned with expectations compared to the original mix. The average 14-day compressive strength for the 0% mix for the re-mix was 2,055 psi, which was much higher than the 523 psi obtained prior. Because these results were rational, the results are much more useful in comparing the 0% mix in the re-mix than the original mix to the 20% and 30% mixes. The average 28-day compressive strengths for the 0%, 20% and 30% mixes for the remix respectively were 2,473 psi, 1,909 psi, and 2,237 psi. This shows that partially substituting cement with natural pozzolans produces similar results to cement based grout. Looking at the varying percent substitutions of natural pozzolan in the mixes, the 30% mix in the remix had a slightly higher 28-day average compressive strength than the 20% mix, but more research would need to be done to conclude decisively what percentage partially substituting the cement yields the best strength.

7. Conclusion

Grout is widely used in the construction industry and will continue to be a prominent component in the future of concrete masonry. The results showed that at 28 days the average compressive strength of the 20% and 30% natural pozzolan mixes were 1,909 psi and 2,237 psi respectively. This data compares well to the purely cement based grout at 28 days at an average compressive strength of 2,473 psi. Given the results of this experiment, using natural pozzolans as a partial substitute for cement in the production of grout produces similar compressive strengths than grout without natural pozzolans. Based off the statistical literature search, natural pozzolan is a more sustainable substitute than imported fly ash as the material emits less pollutants into the atmosphere. Natural pozzolans are domestically sourced rather than shipped from global suppliers, which also creates new jobs for the labor force in the United States and contributes to a thriving economy. Considering sustainability and domestic sourcing, natural pozzolans are a better alternative than fly ash in grout production and should be used as a cement substitute in the future construction of masonry.

8. References

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ASTM Standard C476, 2023, " Standard Specification for Grout for Masonry," ASTM International, West Conshohocken, PA, 2023, <https://compass.astm.org/document/?contentCode=ASTM%7CC0476-23%7Cen-US>

ASTM Standard C143/C143M, 2020, " Standard Test Method for Slump of Hydraulic-Cement Concrete," ASTM International, West Conshohocken, PA, 2020, < https://compass.astm.org/document/?contentCode=ASTM%7CC0143_C0143M-20%7Cen-US>

ASTM Standard C157/C157M, 2017, " Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," ASTM International, West Conshohocken, PA, 2017, <https://compass.astm.org/document/?contentCode=ASTM%7CC0157_C0157M-17%7Cen-US>

"Bulk Density Table - Sawyer/Hanson." (2003). Brabender Technologie, <http://www.sawyerhanson.com/uploads/Brabender%20Ingredient%20bulk%20density%20table.pdf> (accessed 19 April 2023).

DeRousseau, M.A., Arehart, J.H., Kasprzyk, J.R., Srubar III W.V. (2020). “Statistical variation in the embodied carbon of concrete mixtures.” *Journal of Cleaner Production*, 275, Article 123088.

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Ricker, C., Chase, N., Schipper, M., and Hamilton, M. (2019). “More stringent marine sulfur limits mean changes for U.S. refiners and ocean vessels.” *U.S. Energy Information Administration (EIA)*, <https://www.eia.gov/todayinenergy/detail.php?id=38233> (accessed 19 April 2023).

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Volza LLC. (2020). Volza United States Fly ash imports, <https://www.volza.com/p/fly-ash/import/import-in-united-states/> (accessed 22 April 2023).

8.1 Annotated Bibliography

Adams, T. (2022). American Coal Ash Association, <https://acaa-usa.org/wp-content/uploads/2022/12/News-Release-Coal-Ash-Production-and-Use-2021.pdf> (accessed 22 April 2023).

The article published by the American Coal Ash Association documents the coal ash production and usage in the U.S. in tons. The article also shows more specifically fly ash production and usage as well as the recycling rate of the material each year. The report deems it relevant to use data from the article supporting the notion that fly ash production in the U.S. is on the decline.

ASTM Standard C1019, 2020, "Standard Test Method for Sampling and Testing Grout for Masonry," ASTM International, West Conshohocken, PA, 2020, <https://compass.astm.org/document/?contentCode=ASTM%7CC1019-20%7Cen-US>

The standard published by ASTM documents the procedure used in the report with regards to the testing of the grout material. More specifically, the standard lays out the specifics of the required specimen widths and heights. The standard also lays out various methods of how to obtain the grout specimens including the filling of cells in masonry units as in the report. Notably the report makes mention of this standard saying that the specimens will not be in laboratory conditions per Section 3.3.

ASTM Standard C476, 2023, " Standard Specification for Grout for Masonry," ASTM International, West Conshohocken, PA, 2023, <https://compass.astm.org/document/?contentCode=ASTM%7CC0476-23%7Cen-US>

The standard published by ASTM documents the procedure used in the report with regards to the mixing of the grout material. More specifically, the standard lays out the specifics of the required slump of the material (8-11 in) as well as the required time that the materials are to be in the mechanical mixer (5 mins). Notably the standard was unclear whether the 5 minutes of mixing was just the dry mix and 5 more minutes with the water or just 5 minutes total with everything, so a total of 10 minutes was used in the actual procedure in the report.

ASTM Standard C143/C143M, 2020, " Standard Test Method for Slump of Hydraulic-Cement Concrete," ASTM International, West Conshohocken, PA, 2020, < https://compass.astm.org/document/?contentCode=ASTM%7CC0143_C0143M-20%7Cen-US>

The standard published by ASTM documents the procedure used in the report with regards to the slump test of the grout material. More specifically, the standard lays out the specifics of where to measure the slump from (from the center of the top surface of the specimen to the top of the mold), as well as how to record the slump (nearest ¼ inch).

ASTM Standard C157/C157M, 2017, " Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," ASTM International, West Conshohocken, PA, 2017, <https://compass.astm.org/document/?contentCode=ASTM%7CC0157_C0157M-17%7Cen-US>

The standard published by ASTM documents the procedure that is supposed to be followed when storing grout specimens while they cure. Specifically, the standard gives the temperature and humidity that the room is supposed to be maintained at to keep the specimens within laboratory conditions. Notably the report mentioned that its procedure is not following the exact temperature and humidity conditions specified but is following the intent of the standard.

"Bulk Density Table - Sawyer/Hanson." (2003). Brabender Technologie, <http://www.sawyerhanson.com/uploads/Brabender%20Ingredient%20bulk%20density%20table.pdf> (accessed 19 April 2023).

This document displays the bulk density of various structural compounds and materials. This density is distributed in terms of pounds per cubic foot and is published by Brabender Technologies. Brabender is based out of Ontario Canada and the company has over 60 years of experience and expertise in the handling of bulk materials. This is relevant to this report in that by using these bulk densities one can deduce the volume of materials in question.

DeRousseau, M.A., Arehart, J.H., Kasprzyk, J.R., Srubar III W.V. (2020). “Statistical variation in the embodied carbon of concrete mixtures.” *Journal of Cleaner Production*, 275, Article 123088.

The article written by DeRousseau et al demonstrates the various factors that contribute to embodied carbon in concrete and grout production. Specifically the article weighs the alternatives of using no fly ash in concrete and grout applications and transporting fly ash from Asia(Shenzhen, China) to New York City. The article considers distance, transportation methods and the amount of cargo the given transportation method can hold. The relevant conclusion to the report is that transporting fly ash from long distances via cargo ships can cancel out the benefits the material has on reducing embodied carbon production. Even more, distances such as from Shenzhen, China to New York City can make the embodied carbon 4% higher in concrete with fly ash, versus concrete without fly ash. The article confirms the report’s claims that transporting fly ash from foreign countries into the U.S isn’t sustainable.

Hooton, D., and Thomas, N. (2021). American Coal Ash Association, <https://acaa-usa.org/wp-content/uploads/2022/12/Harvested-fly-ash-Report-Oct-15-2021-rev-Oct-31.pdf> (accessed 22 April 2023).

The article written by Hooton et al investigates the use of “harvested” fly ash, bottom ash, as well as mixtures of the two. Harvested fly ash is fly ash taken from storage facilities such as landfills and lagoons. Bottom ash is ash in the coal combustion process that sinks to the bottom of the plant as it has a higher density

than fly ash. Harvested fly ash and bottom ash are examples of ashes that have previously not been used in concrete and grout applications. This article concludes that with some mining techniques and some grinding down of materials, “harvested” fly ash and bottom ash are adequate for use in concrete and grout applications. This is relevant to the report as the use of these materials is another solution to declining fly ash production as opposed to the use of natural pozzolans considered in the report. The report talks about the advantages and disadvantages of the use of these materials as opposed to natural pozzolans.

Ortiz, A. (2022). “Tonnage in shipping - gross tonnage, Net Tonnage & Displacement.” Drip Capital Inc., <https://www.dripcapital.com/en-us/resources/blog/tonnage-in-shipping> (accessed 19 April 2023).

This online article was published by Drip Capital Inc. out of Palo Alto in California. Drip Capital Inc. uses advanced statistical models and predictive algorithms on extensive data sets to identify financing opportunities. In this document, the understanding of tonnage in the shipping industry is explained. This small calculation of tonnage gives us a relatively close understanding of the carrying capacity of a standard fly ash freighter ship. This is a vital piece of data that is required for determining the economic and environmental impacts and advantages of different methods of shipping or sourcing.

Ricker, C., Chase, N., Schipper, M., and Hamilton, M. (2019). "More stringent marine sulfur limits mean changes for U.S. refiners and ocean vessels." U.S. Energy Information Administration (EIA), <https://www.eia.gov/todayinenergy/detail.php?id=38233> (accessed 19 April 2023).

This Article is published by the U.S. Energy Information Administration based out of Washington DC in 2019. This paper goes into great detail on the United States and the implementation of new regulations affecting marine fuel. This is a key concept when comparing the emissions and pollutants from shipping in the U.S. and then from other foreign nations. These new regulations are only present in the United States and have been on the rise since 2012.

Rodrigue, J.-P. (2022). "Fuel consumption by containership size and speed: The Geography of Transport Systems." The Geography of Transport Systems | The spatial organization of transportation and mobility, <https://transportgeography.org/contents/chapter4/transportation-and-energy/fuel-consumption-containerships/> (accessed 19 April 2023).

This paper was published by Dr. Jean Rodrigue who is a professor of geography at Hofstra University. In this paper Dr. Rodrigue shares a detailed comparison of different vessel sies and the relative bunker fuel consumption. This allows for a comparison to be made of different sized ships and the pollutants given off. This also permits a range of fuel consumption per speed of travel. By knowing this information, links can be made between the ship fuel burn rate and that of other means of shipment.

Seo. (2018). “Understanding the differences between diesel fuel grades.” Kendrick Oil, <https://kendrickoil.com/understanding-differences-diesel-fuel-grades/> (accessed 19 April 2023).

This article is by SEO and comes from Kendrick Oil Company. In the article Diesel #2 is discussed and defined. This is relevant to the Research project in that long haul trucks use this type of fuel. This is vital information when comparing the pollutants and usage of bunker fuel to this grade of diesel. Kendrick Oil has been in the oil business since 1951 and has been a proud producer of oil in America ever since. This company’s credibility comes from the fact that they have worked in this industry for 72 years and have built a reputation for quality.

Team, T. T. (2021). “Semi-trailer dimensions, length & what can you haul.” www.transwest.com, <https://www.transwest.com/trailers/blog/semi-trailer-dimensions-length-and-what-can-you-haul/> (accessed 19 April 2023).

This online article was produced by the Transwest Trailer Company. This company has been in the trailer building, selling, and renting business since 1992. Published in 2021, this article explains the different types of trailers used in long haul shipping. This article also goes into detail on trailer dimensions and different trailer specifications that might change from trailer to trailer. This is key data when it comes to figuring out what the maximum load for a desired trailer is. Knowing the volume of a given trailer as well as the density of natural pozzolans, one can figure out the weight of natural pozzolans a given trailer can hold. The Transwest Company also shares some regulations put in by states to limit the weight per trailer. For tri-axial trailers, a maximum of 65,000 lbs can be hauled. These regulations come into play since natural pozzolans are heavy and are accounted for in the report's analysis.

"Tephra RFA - CR Minerals." (n.d.). CRMinerals, CRMinerals, <https://www.crminerals.com/PDF/products/Tephra_RFA_Technical_Data_Sheet_12-16-19.pdf> (accessed 19 April 2023).

This online article and data sheet is published by CR Minerals. In this article CRMinerals explain what natural pozzolans are and why they are used. They examine the benefits of the use and give a brief explanation of each. In this article there is also a technical information summary that not only gives the bulk density of the pozzolan but also the ASTM references to the specifications. This bulk density is used in the analysis in this report.

U.S General Services Administration. (2023). U.S General Services Administration Sustainable Design, <https://www.gsa.gov/real-estate/design-and-construction/sustainability/sustainable-design> (accessed 22 April 2023).

This online article published by the U.S General Services Administration gives a relevant definition of sustainable design in that it seeks to "reduce consumption of non-renewable resources". The report uses this definition to argue that the use of fly ash is not sustainable in the U.S as it is increasingly becoming a non-renewable resource due to declining domestic fly ash production.

United States Environmental Protection Agency. (2022). United States Environmental Protection Agency Frequent Questions about the 2015 Coal Ash Disposal Rule, <https://www.epa.gov/coalash/frequent-questions-about-2015-coal-ash-disposal-rule> (accessed 22 April 2023).

This online article published by the U.S Environmental Protection Agency gives how many coal ash landfills and ash ponds are currently active in the U.S. This fact is relevant to the report as the large amount of storage facilities of coal ash means the use of this remaining coal ash is a good solution for the time being to the declining domestic fly ash production problem, but the use of natural pozzolans is still vital in the future when the limited supply at the storage facilities runs out.

Volza LLC. (2020). Volza United States Fly ash imports, <https://www.volza.com/p/fly-ash/import/import-in-united-states/> (accessed 22 April 2023).

This website gives information regarding fly ash imports and exports from various countries based off tracking different ports around the world. It is relevant to the report as it documents where the U.S gets most of its imported fly ash from (South Korea, India, Turkey). Knowing these countries helps establish the transportation distances required for transporting fly ash to the U.S and how efficient importing fly ash into the U.S is compared to domestically transporting natural pozzolans.

8.1 Annotated Sources

For Immediate Release

ACAA
AMERICAN COAL ASH ASSOCIATION

Contact: **American Coal Ash Association**
Thomas H. Adams, Executive Director
Office: 720-870-7897 Mobile: 720-375-2998
thadams@acaa-usa.org
www.acaa-usa.org

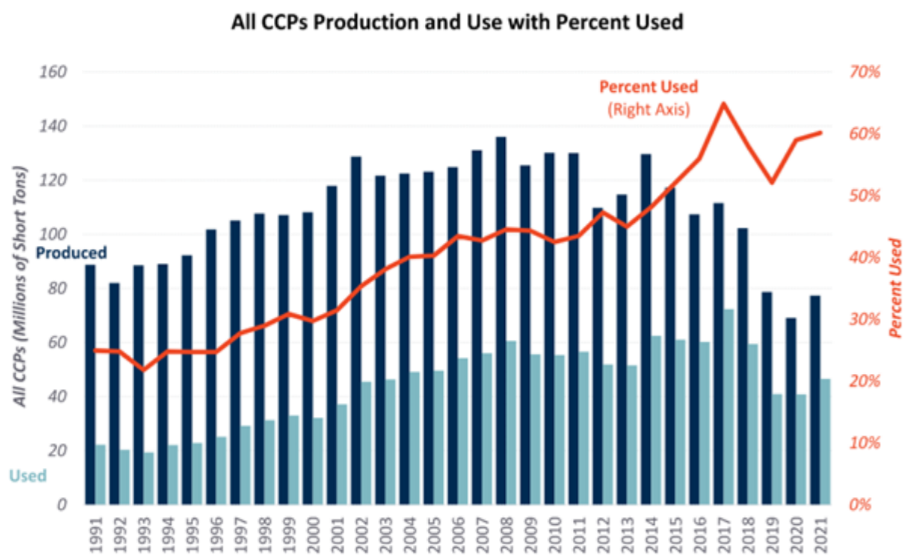
Coal Ash Recycling Rate Increases Slightly in 2021; Use of Harvested Ash Grows Significantly

December 6, 2022 – Sixty percent of the coal ash produced during 2021 was recycled – increasing from 59 percent in 2020 and marking the seventh consecutive year that more than half of the coal ash produced in the United States was beneficially used rather than disposed.

American Coal Ash Association ("ACAA") today released its annual "Production and Use Survey" which also showed that use of harvested ash is continuing to grow. Nearly 4.5 million tons of previously disposed ash was utilized in a variety of applications in 2021, including coal ash pond closure activities, concrete products, cement kiln raw feed, and gypsum panel manufacturing. The volume of harvested ash that was utilized increased 12 percent, or more than 500,000 tons, over the previous year.

"Harvested ash utilization volumes now equal nearly 10 percent of the volume of ash recycled from current power plant operations," said Thomas H. Adams, ACAA Executive Director. "The rapidly increasing utilization of harvested coal combustion products ("CCP") shows that beneficial use markets are adapting to the decline in coal-fueled electricity generation in the United States. New logistics and technology strategies are being deployed to ensure these valuable resources remain available for safe and productive use. We must continue to support these practices that safely conserve natural resources while dramatically reducing the need for landfills."

According to ACAA's 2021 survey, 46.5 million tons of coal combustion products were beneficially used in 2021, an increase of nearly 6 million tons over the previous year. Production of new CCP also increased from 69.1 million tons in 2020 to 77.3 million tons in 2021 as utilities consumed more coal for generating electricity.


All CCPs Production and Use with Percent Used
Percent Used
(Right Axis)
All CCPs (Millions of Short Tons)
Produced
Used
Percent Used
0
20
40
60
80
100
120
140
160
0%
10%
20%
30%
40%
50%
60%
70%
1991
1992
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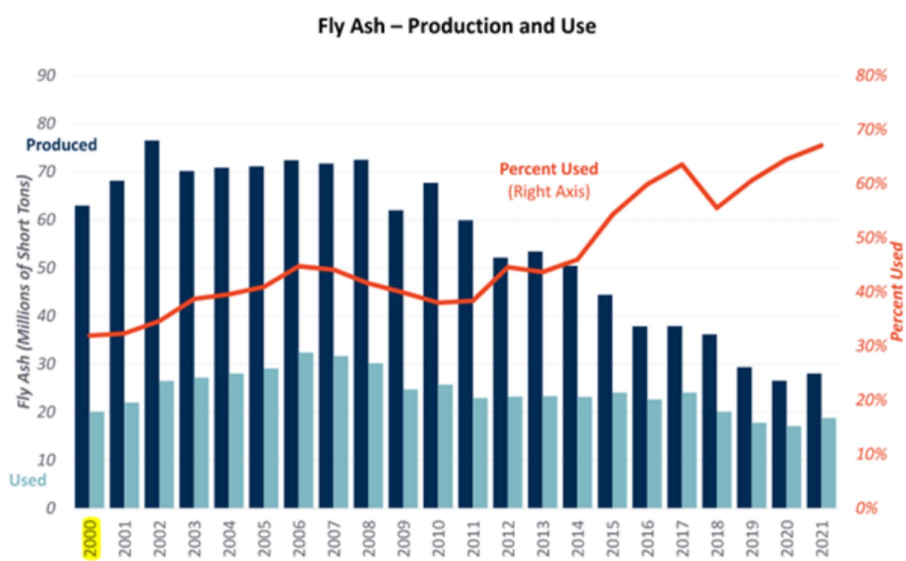
Fly Ash – Production and Use
Fly Ash (Millions of Short Tons)
Produced
Used
Percent Used
(Right Axis)
Percent Used
0
10
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50
60
70
80
90
0%
10%
20%
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2021 Coal Combustion Product (CCP) Production & Use Survey Report

Beneficial Utilization versus Production Totals (Short Tons)

2021 CCP Categories	Fly Ash	Bottom Ash	Boiler Slag	FGD Gypsum	FGD Material Wet Scrubbers	FGD Material Dry Scrubbers	FGD Other	FBC Ash	CCP Production / Utilization Totals
Total CCPs Produced by Category	**28,004,916**	**8,783,796**	**1,195,311**	**19,688,381**	**7,032,003**	**4,284,941**	**63,578**	**8,310,124**	**77,363,050**
Total CCPs Used by Category	**18,787,042**	**3,591,948**	**734,652**	**14,890,701**	**0**	**226,109**	**0**	**8,310,124**	**46,540,576**
1. Concrete/Concrete Products /Grout	11,936,154	617,000	0	32,395	0	38,183	0	0	12,623,732
2. Blended Cement/ Feed for Clinker	3,291,107	773,999	103,884	1,430,135	0	0	0	0	5,599,124
3. Flowable Fill	48,687	0	0	0	0	0	0	0	48,687
4. Structural Fills/Embankments	198,746	1,698,855	145,869	0	0	0	0	0	2,043,469
5. Road Base/Sub-base	74,702	95,608	0	0	0	0	0	0	170,309
6. Soil Modification/Stabilization	103,207	0	0	0	0	0	0	0	103,207
7. Mineral Filler in Asphalt	7,544	0	0	0	0	0	0	0	7,544
8. Snow and Ice Control	0	56,311	3,655	0	0	0	0	0	59,965
9. Blasting Grit/Roofing Granules	0	52,452	481,245	0	0	0	0	0	533,697
10. Mining Applications	87,636	0	0	0	0	31,465	0	8,310,124	8,429,225
11. Gypsum Panel Products (formerly Wallboard)	0	0	0	11,740,314	0	0	0	0	11,740,314
12. Waste Stabilization/Solidification	433,456	53,243	0	977	0	13,587	0	0	501,263
13. Agriculture	0	3,516	0	742,546	0	76,839	0	0	822,902
14. Aggregate	1,843	43	0	453,114	0	0	0	0	455,000
15. Oil/Gas Field Services	55,677	0	0	0	0	15,696	0	0	71,373
16. CCR Pond Closure Activities	2,351,905	150,696	0	449,700	0	0	0	0	2,952,301
17. Miscellaneous/Other	196,378	90,226	0	41,520	0	50,339	0	0	378,462

Summary Utilization to Production Rate

CCP Categories	Fly Ash	Bottom Ash	Boiler Slag	FGD Gypsum	FGD Material Wet Scrubbers	FGD Material Dry Scrubbers	FGD Other	FBC Ash	CCP Utilization Total
Totals by CCP Type/Application	18,787,042	3,591,948	734,652	14,890,701	0	226,109	0	8,310,124	**46,540,576**
Category Use to Production Rate (%)	**67.08%**	**40.89%**	**61.46%**	**75.63%**	**0.00%**	**5.28%**	**0.00%**	**100.00%**	**60.16%**
2021 Cenospheres Sold (Pounds)	107,835	**Data in this survey represents 115.36786 GWs of Name Plate rating of the total industry wide approximate 210.141 GW capacity based on EIA's July 2021 Electric Power Monthly.**							

Designation: C1019 – 20

Standard Test Method for Sampling and Testing Grout for Masonry[1]

This standard is issued under the fixed designation C1019; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method covers procedures for both field and laboratory sampling and compression testing of grout used in masonry construction. Grout for masonry is specified under Specification C476.

NOTE 1—The testing agency performing this test method should be evaluated in accordance with Practice C1093.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C476 Specification for Grout for Masonry
C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
C617 Practice for Capping Cylindrical Concrete Specimens
C1064/C1064M Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete
C1093 Practice for Accreditation of Testing Agencies for Masonry
C1611/C1611M Test Method for Slump Flow of Self-Consolidating Concrete

3. Significance and Use

3.1 Grout used in masonry is a fluid mixture of cementitious materials and aggregate with a high water content for ease of placement.

3.1.1 During construction, grout is placed within or between absorptive masonry units. Excess water must be removed from grout specimens in order to provide compressive strength test results more nearly indicative of the grout strength in the wall. In this test method, molds are made from masonry units having the same absorption and moisture content characteristics as those being used in the construction.

3.2 This test method is used to either help select grout proportions by comparing test values or as a quality control test for uniformity of grout preparation during construction.

3.3 The physical exposure condition and curing of the grout are not exactly reproduced, but this test method does subject the grout specimens to absorption conditions similar to those experienced by grout in the wall.

NOTE 2—Test results of grout specimens taken from a wall should not be compared to test results obtained with this test method.

4. Apparatus

4.1 *Maximum-Minimum Thermometer.*

4.2 *Straightedge,* a steel straightedge not less than 6 in. (152.4 mm) long and not less than 1⁄16 in. (1.6 mm) in thickness.

4.3 *Tamping Rod,* a round, straight, steel rod with a diameter of 3⁄8 ± 1⁄16 in. (10 ± 2 mm) and a length of 12 ± 4 inches. (300 ± 100 millimetres). The rod shall have the tamping end or both ends rounded to a hemispherical tip of the same diameter as the rod.

[1] This test method is under the jurisdiction of ASTM Committee C12 on Mortars and Grouts for Unit Masonry and is the direct responsibility of Subcommittee C12.02 on Research and Methods of Test.

Current edition approved Dec. 1, 2020. Published December 2020. Originally approved in 1984. Last previous edition approved in 2019 as C1019 – 19. DOI: 10.1520/C1019-20.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

1

4.4 *Nonabsorbent Blocks and Spacers,* nonabsorbent, rigid squares and rectangles with side dimensions so as to achieve the desired grout specimen side dimensions and of sufficient quantity or thickness to yield the desired grout specimen height, as shown in Fig. 1, Fig. 2, and Fig. 3.

NOTE 3—Nonabsorbent blocks may be of plastic, wood, or other nonabsorbent material. Certain species of wood contain sugars which cause retardation of cement. In order to prevent this from occurring, new wooden blocks shall be soaked in limewater for 24 h, sealed with varnish or wax, or covered with an impermeable material prior to use.

4.5 *Framing Square,* a framing square not less than 6 in. (150 mm) long and not less than 1⁄16 in. (2 mm) in thickness.

4.6 *Panels and plates*, pieces of ¾ in. (19 mm) plywood with dimensions as needed to contain units and grout specimens. Soak in limewater for 24 h, seal with varnish or wax, or cover with an impermeable material prior to use. A nonabsorbant material of equivalent stiffness to the plywood is permitted.

PROCEDURES

5. Grout Specimen Molds

5.1 *Molds from Masonry Units:*

5.1.1 Select a level location where the molds remain undisturbed for up to 48 h.

NOTE 4—The location of specimen construction should be protected and as free from perceptible vibration as possible.

5.1.2 The construction of the mold shall simulate the in-situ construction. If the grout is placed between two different types of masonry units, both types shall be used to construct the mold.

5.1.3 Form specimen molds by arranging masonry units of the same type and moisture condition as those being used in the construction. The surface of the units in contact with the grout specimen shall not have been previously used to mold the specimens. Place a non-absorbent block as described in 4.4, cut to the proper size and of the proper thickness or quantity, at the bottom of the space to achieve the necessary height of the specimen. Specimen molds shall comply with the following:

5.1.3.1 Molds shall have a cross-section that is nominally square.

5.1.3.2 Molds shall have a width of 3.0 in. (76 mm) to 3.75 in. (95 mm).

5.1.3.3 Molds shall have a height of at least twice the width (see Note 5).

NOTE 5—The final specimen height requirement is defined in 5.1.3 as being 1.75 to 2.0 times the specimen width. The intent of the standard is to target a specimen height two times the specimen width while allowing some tolerance in those cases where the specimen would need to be cut down in height to meet the perpendicularity requirements. Having a mold that has a height at least twice the specimen width allows the final specimen to be meet the requirement or be cut to meet the requirement.

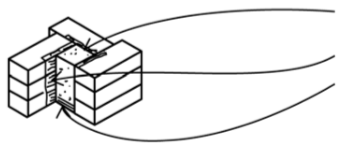

FIG. 1 Example of Grout Mold (Units 6 in. (152.4 mm) or Less in Height, 2¼ in. (57.2 mm) High Brick Shown)

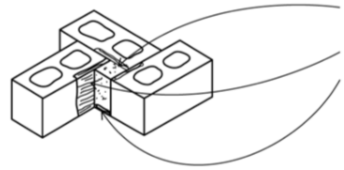

FIG. 2 Example of Grout Mold (Units Greater than 6 in. (152.4 mm) High, 8 in. (203.2 mm) High Concrete Masonry Unit Shown)

5.1.4 Line the masonry surfaces that will be in contact with the grout specimen with a thin, permeable material to prevent bond to the masonry units. New lining material shall be used for each specimen.

NOTE 6—The lining, such as paper towel, is used to aid in stripping the grout specimen from the mold. Proper installation of the lining prevents irregularly sized specimens and varying test results.

5.1.5 See Figs. 1-3 and accompanying notes for example of mold construction that conform with 5.1.2, 5.1.3, and 5.1.4.

5.1.6 Brace units to prevent displacement during grouting and curing.

5.2 *Alternative Methods*—Alternative methods of forming the specimens shall be used only with the approval of the specifier. Such approval shall be based on comparative testing of grout specimens constructed from molds as described in 5.1 and the alternative method. Approval shall be limited to a single specimen shape, method of forming, masonry units used, and grout mix. A conversion factor based on comparative testing of a minimum of ten pairs of specimens shall be used to modify results from alternative methods. The coefficient of variation of test results of specimens formed by the alternative method shall be less than or equal to that of the specimens formed in accordance with 5.1.

NOTE 7—Other methods of obtaining grout specimens and specimens of different geometry have been employed in grout testing, but are not described in this test method. Other methods used to obtain grout specimens include: drilling grout-filled cores of regular units; filling cores of masonry units specifically manufactured to provide grout specimens; filling compartments in slotted corrugated cardboard boxes specifically manufactured to provide grout specimens; and forming specimens from different sized masonry units of the same or similar material.

Since test results vary with methods of forming the specimen, specimen geometry, and grout mix, comparative test results between specimens made with molds described in 5.1 and specimens made with alternative methods are required and confined to a single specimen shape, method of forming, masonry units used, and grout mix.

6. Test Specimens

6.1 Specimens shall comply with the following:

6.1.1 Specimens shall have a nominally square cross section.

6.1.2 Specimens shall have an average specimen width between 3 in. (76 mm) and 3.75 in. (95 mm).

6.1.3 Specimens shall have a height before capping between 1.75 and 2.0 times the specimen width.

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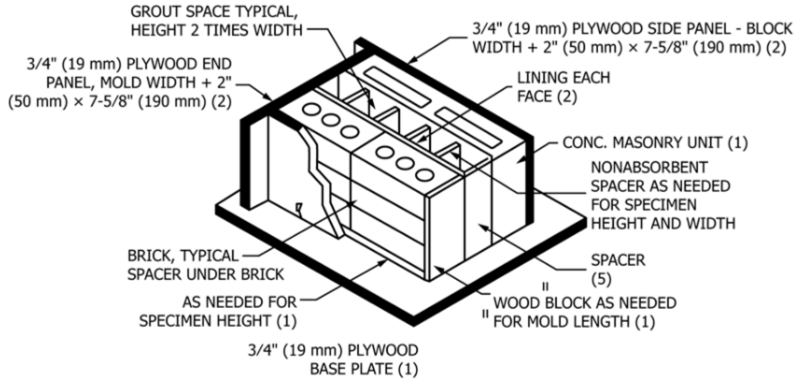

FIG. 3 Example of Grout Mold with Brick and Concrete Masonry Units

6.1.4 For each specimen, the difference between any width measurement and the average width for that specimen shall not exceed ⅛ in. (3.2 mm).

6.1.5 Neither end of the test specimen shall depart from perpendicularity to the vertical axis by more than 1 degree (approximately equivalent to ⅛ in. in 6 in.) (1 mm in 50 mm).

6.1.6 Specimens shall have side surfaces that are plane to within ⅛ in. in 6 in. (1 mm in 50 mm). See Fig. 4.

NOTE 8—Subsection 10.7 provides for cutting or grinding the top or bottom of hardened specimens to achieve dimensional requirements.

6.2 Test at least three specimens at each age specified.

NOTE 9—Frequency of sampling and age of test is to be determined by the specifier of this test method and is usually found in the construction documents.

7. Sampling Grout

7.1 *Size of Sample*—Grout samples to be used for slump and compressive strength tests shall be a minimum of ½ ft^3 (0.014 m^3).

7.2 *Procedure*—The procedures used in sampling shall include the use of precautions that will assist in obtaining samples that are representative of the nature and condition of

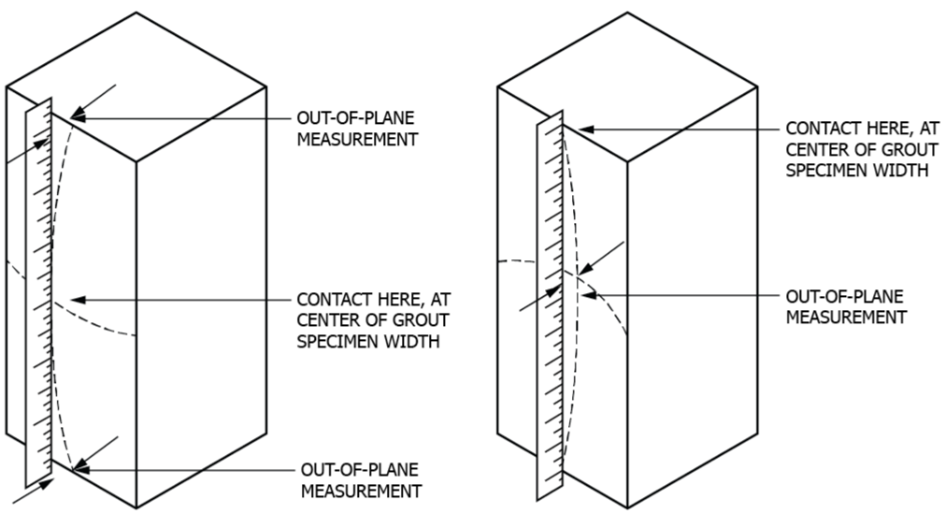

FIG. 4 Out-of-plane Measurement

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the grout. After the final slump adjustment has been made, sample grout as the grout is being placed.

7.2.1 *Field Sampling*—Collect two or more portions taken at regularly spaced intervals during the discharge of the middle portion of the batch. The elapsed time between obtaining the first and final portions of the sample shall be not more than 15 min.

7.2.2 *Laboratory Sampling*—The entire mixed batch of grout is the sample.

NOTE 10—The field technician sampling, making, and curing specimens for acceptance testing should be certified (American Concrete Institute Field Testing Technician—Grade I, National Concrete Masonry Association Masonry Testing Technician, or equivalent). Equivalent certification programs should include both written and performance examinations.

7.3 Place the grout sample in a non-absorptive container and cover the top to protect the sample from the sun, wind, and any other sources of rapid evaporation and from contamination. Transport the grout sample to the mold location. Remix the sample with a shovel or trowel to ensure uniformity prior to filling molds. Keep remaining grout sample protected in a covered, non-absorptive container until used to fill any depression in the sample due to initial water loss.

8. Temperature and Slump Test

8.1 Measure and record the temperature of the grout sample in accordance with Test Method C1064/C1064M.

8.2 Begin filling the slump cone within 5 min of obtaining the final portion of the sample.

8.3 For all grout except self-consolidating grout, measure and record the slump in accordance with the requirements of Test Method C143/C143M.

8.4 For self-consolidating grout, measure and record the slump flow in accordance with the requirements of Test Method C1611/C1611M and visual stability index (VSI) in accordance with the requirements of Test Method C1611/C1611M, Appendix X1.

9. Compressive Test Specimen

9.1 If grout from the slump or slump flow test is used for the compressive test specimens, remix the sample. Begin filling the compressive strength molds within 15 min of obtaining the final portion of the sample.

9.2 For all grout except self-consolidating grout, fill the mold with grout in two layers of approximately equal depth. Rod each layer 15 times with the tamping rod. Rod the bottom layer through its depth. Slightly overfill the mold. Rod the second layer with the tamping rod penetrating approximately ½ in. (12.7 mm) into the lower layer. Distribute the strokes uniformly over the cross section of the mold.

9.3 For self-consolidating grout, fill the mold with grout in one layer and do not rod.

9.4 Strike off the top surface of the specimen with a straightedge to produce a flat surface that is even with the top edge of the mold and that has no depressions or projections larger than ⅛ in. (3.2 mm). Cover immediately with a damp absorbent material such as cloth or paper towel. Keep the top surface of the specimens damp by wetting the absorbent material and covering with a nonabsorbent, nonreactive material to retain the moisture. Do not disturb the specimens.

9.5 Between 15 and 30 min after filling the mold, add sufficient grout without rodding to fill the depression caused by initial water loss. Strike off the top surface of the specimen with a straightedge to produce a flat surface that is even with the top edge of the mold. Cover immediately with a damp absorbent material such as cloth or paper towel. Keep the top surface of the specimen damp by wetting the absorbent material and covering with a nonabsorbent, nonreactive material. Do not disturb the specimen until the molds are removed.

NOTE 11—The viscosity of self-consolidating grout changes with time. Thus the depression may require filling prior to the thirty minute limit.

9.6 Protect the specimens from freezing and variations in temperature. Store an indicating maximum-minimum thermometer with the specimens and record the maximum and minimum temperatures experienced prior to the time the specimens are placed in the final curing environment.

NOTE 12—If storage temperatures are less than 60°F (15.6°C) or greater than 80°F (26.7°C) as shown by the thermometer, the resulting compressive strength will likely be affected.

10. Transportation, Curing, and Testing of the Specimens

10.1 Remove the molds between 24 and 48 h after making the specimens.

NOTE 13—Various conditions, such as the use of set retarders or low ambient temperatures, may necessitate delaying mold removal until well after 24 h. Care should be taken to ensure the specimens have achieved sufficient strength for transportation, which may include delaying mold removal and transportation until 48 h.

10.2 Within 30 min after removing the molds, place specimens in a protective container and keep specimens damp.

10.3 Transport field specimens to the laboratory within 8 h after mold removal.

10.4 Within 8 h after mold removal, place in a moist room, moist cabinet, or water storage tank conforming to Specification C511. Store there until day of testing.

10.5 Keep specimen damp until tested.

10.6 *Specimen Measurement:*

10.6.1 Measure and record the width of all four faces at mid-height to the nearest ¹⁄₁₆ in. (2 mm).

10.6.2 Measure and record the height of all four faces at mid-width to the nearest ¹⁄₁₆ in. (2 mm).

10.6.3 Measure and record the perpendicularity from the top and bottom surfaces at mid-width of each face to the nearest ¹⁄₁₆ in. (2 mm). See Fig. 5.

10.6.4 Measure and record the amount out-of-plane at mid-width of each side surface to the nearest ¹⁄₁₆ in. (2 mm). See Fig. 5. Specimens that are beyond the out-of-plane tolerances shall not be tested.

10.7 It is permissible to cut or grind the top, bottom or both of specimens that are beyond the tolerances listed in 6.1.3 or 6.1.5 prior to capping and testing the specimens provided the resulting ratio of average height to average width (h/w) is between 1.75 and 2.0. Reported measurements shall be based on measurements after cutting or grinding is completed.

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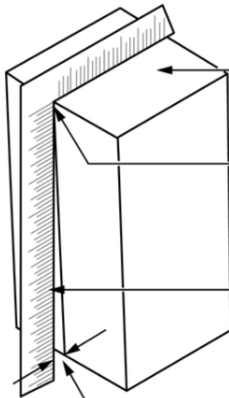


FIG. 5 Perpendicularity Measurement

10.8 Cap the specimens in accordance with the applicable requirements of Practice C617.

NOTE 14—Practice C617 refers to capping cylindrical specimens; therefore, the alignment devices may need to be modified to ensure proper use with the rectangular prism specimens of this method. All other sections of Practice C617 are applicable.

10.9 Test the specimens in a damp condition in accordance with the applicable requirements of Test Method C39/C39M.

11. Calculations

11.1 Determine the average width by averaging the four width measurements. Determine the average height by averaging the four height measurements.

11.2 Determine the average cross-sectional area by calculating the average width of opposite faces, and multiplying the averages.

11.3 For specimens from molds of masonry units, calculate the compressive strength by dividing the maximum load by the average cross-sectional area and express the result to the nearest 10 psi (50 kPa).

11.4 For specimens from alternative methods of forming, calculate a conversion factor between the results obtained from comparative testing by dividing the average compressive strength of the specimens formed in accordance with 5.1 by the average compressive strength of the specimens formed by the alternative method. Calculate the average corrected compressive strength by dividing the maximum load by the average cross-sectional area and multiplying the result by the conversion factor. Express the result to the nearest 10 psi (50 kPa).

11.5 When specimens are formed using alternative methods as described in 5.2, calculate the coefficient of variation for results obtained from comparative testing by dividing the standard deviation of each method by its mean.

12. Report

12.1 For all specimens, the report shall include the following (see Note 15):

NOTE 15—See Appendix X1 for an example of a report.

12.1.1 Grout mix design,

12.1.2 Grout slump for all grouts except self-consolidating grout,

12.1.3 Slump flow and visual stability index (VSI) value of the grout for self-consolidating grout,

12.1.4 Description of the specimens—individual and average width and height dimensions.

12.1.5 Curing history, including initial temperature, maximum and minimum temperatures, and age of specimens when transported to laboratory and when tested,

12.1.6 Maximum load and compressive strength of each specimen, average compressive strength of the specimens, and standard deviation, and

TABLE 1 Statistics of Laboratory-Prepared Specimens

Number of Specimens	Mean, psi (MPa)	Standard Deviation, psi (MPa)	Coefficient of Variation, %
3	4196 (28.9)	73.8 (0.51)	1.18
3	4455 (30.7)	50.8 (0.35)	1.87
3	6014 (41.5)	323 (2.28)	5.25
3	6196 (42.7)	148 (1.02)	2.38
3	7292 (50.3)	600 (4.14)	8.23
5	3784 (26.1)	306 (2.11)	8.1
5	2494 (17.2)	220 (1.52)	8.8
5	3178 (21.9)	634 (4.37)	20.0
6	5480 (37.8)	899 (6.2)	16.4
10	5350 (36.9)	826 (5.7)	15.4
12	3872 (26.7)	333 (2.30)	8.6
15	3468 (23.9)	154 (1.06)	4.46
15	3478 (24.0)	253 (1.75)	7.27
20	2617 (18.1)	127 (0.88)	4.85
20	2627 (18.12)	125 (0.86)	4.76

TABLE 2 Statistics of Field-Prepared Specimens

Number of Specimens	Mean, psi (MPa)	Standard Deviation, psi (MPa)	Coefficient of Variation, %
3	3583 (24.7)	118 (0.81)	3.3
6	5455 (37.6)	324 (2.23)	5.9
6	3992 (27.5)	228 (1.57)	5.7

12.1.7 Description of failure.

12.2 For specimens from molds of masonry units, additionally report the following:

12.2.1 Type and number of units used to form mold for specimens.

12.3 For specimens from alternative methods of forming, additionally report the following:

12.3.1 Description of the method used,

12.3.2 Conversion factor used to account for differences in method of forming and reference to supporting documentation of conversion factor determination, if not based on results included in this test report, and

12.3.3 Average corrected compressive strength.

12.3.4 Coefficient of variation of the compressive strengths of the specimens formed in accordance with 5.1 and the alternative method for those tests from which the conversion factor is determined.

13. Precision and Bias

13.1 *General:*

13.1.1 The materials used to form the mold have different absorption rates and will remove slightly different amounts of water from each specimen. Thus the standard deviation for this test method is higher than when using a nonabsorbent mold.

13.1.2 The standard deviation from field specimens of grout will be higher than that for laboratory-prepared specimens. There is less control of grout ingredients, conditions of the molds, and initial curing environment in field-prepared specimens.

13.2 *Precision*—The repeatability standard deviation has not been determined in accordance with ASTM procedures. The reproducibility of the procedure in Test Method C1019 for measuring compressive strength is being determined and will be available on or before December 2015. It is not feasible to specify the reproducibility of the procedure at this time because of the variables in specimen preparation and curing.

13.3 *Bias*—No information can be presented on the bias of the procedure in Test Method C1019 for measuring the compressive strength of grout because no material having an accepted reference value is available.

13.4 Limited test data are available for analysis at this time. A more detailed statement will be provided later. The following summary of available data is provided for review.

13.4.1 *Laboratory-prepared Specimens*—The coefficients of variation for a series of laboratory-prepared specimens ranged from 1.18 % with a mean value of 4196 psi (28.9 MPa) to 20.0 % with a mean value of 3178 psi (21.9 MPa). The standard deviations for those values were 73.8 psi (0.51 MPa) and 634 psi (4.37 MPa), respectively. Additional tests on laboratory specimens had the characteristics found in Table 1.

13.4.2 *Field Specimens*—Test reports from one project show the characteristics found in Table 2.

14. Keywords

14.1 cementitious; compressive strength; grout; masonry units

APPENDIX

(Nonmandatory Information)

X1. TEST REPORT FOR GROUT

X1.1 Fig. X1.1, included in this section is a sample test report form for Sampling and Testing Grout for Masonry. This report form is to be used as a guideline only. Users of this test method may use or modify this report form to suit their purposes and to address the requirements of additional test methods that may apply.

C1019 – 20

ASTM C1019 Test Report
Standard Test Method for Sampling and Testing Grout

Date Issued: 01/23/2019
Job Number: 1738

Client: Drive sand Geotech
Address: 1476 Concrete Gold Street,
Pacific Ocean, USA, 01234.

Testing Agency: Accurate Testing Labs
Address: 1738 Stash Avenue,
Oceanway, USA, 41941.

Standard Specification: ASTM C476
Specified Strength: 2,000 psi
Specimen Description: 3.5 × 3.5 × 7.0 Inches
Grout Mix Design: 1 Part Portland to 3 Parts Fine aggregate

Sampling party: GFP
Sample Identification: North End
Date Samples Received: 12/17/2018
Project Identification: Standard Run

Field Test Results
Date Tested: 12/17/18
Slump of Grout: 9.25 inches
Temperature of Grout: 77°F

Curing History: Specimens covered in field with insulating and waterproof material. Specimens cured per C511 in laboratory.

Initial Temperature: 74°F
Maximum Temperature: 77°F
Minimum Temperature: 69°F

Laboratory Test Results

Specimen ID	Cut or ground? (Cut, ground, or NA)	Height 1 (in)	Height 2 (in)	Height 3 (in)	Height 4 (in)	Width 1 (in)	Width 2 (in)	Width 3 (in)	Width 4 (in)	Average Height (in)	Average width (in)	Cross Sectional Area (in^2)	Perpendicularity (in)	Planeness (in)	Date Evaluated
A	NA	7 1/16	7 1/16	7 1/16	7 1/16	3 8/16	3 7/16	3 8/16	3 7/16	7 1/16	3 8/16	12.25	1/16	1/16	01/14/19
B	NA	7	7 1/16	7 1/16	7 1/16	3 8/16	3 8/16	3 8/16	3 8/16	7 1/16	3 8/16	12.25	1/16	1/16	01/14/19
C	NA	6 15/16	6 15/16	6 15/16	6 15/16	3 9/16	3 9/16	3 9/16	3 9/16	6 15/16	3 9/16	12.69	1/16	1/16	01/14/19
D	NA	7	7	7 1/16	7	3 8/16	3 8/16	3 8/16	3 8/16	7	3 8/16	12.25	1/16	1/16	01/14/19

Specimen ID	Age Transported. (hours)	Age Tested. (days)	Max. Load (lb)	Compressive Strength. (psi)	Description of Failure	Date Tested
A	24	28	31,120	2,540	Vertical columnar cracking through both ends	01/14/19
B	24	28	31,848	2,600	Vertical columnar cracking through both ends	01/14/19
C	24	28	30,564	2,410	Vertical columnar cracking through both ends	01/14/19
D	24	28	31,244	2,550	Vertical columnar cracking through both ends	01/14/19
Average Compressive Strength: 2,530 psi			Standard Deviation: 71 psi			

Specimens from molds of Masonry Units
Type of Masonry Units: Concrete Stretcher Blocks (8 in. × 8 in. × 16 in.)
Number of units: 10

Specimens from Alternative Method
Alternative method used: NA
Conversion factor used: NA
Average Corrected Compressive Strength: NA
Co-efficient of variation: NA

Remarks:______________________________

Signature of Laboratory Official

FIG. X1.1 Sample Test Report

7

C1019 – 20

Designation: C476 – 23

Standard Specification for Grout for Masonry[1]

This standard is issued under the fixed designation C476; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This specification covers two types of grout, fine and coarse grout, for use in the construction of masonry structures. Each type (fine and coarse) is further classified as conventional grout (requiring mechanical consolidation by puddling or vibration when placed) and self-consolidating grout (not requiring mechanical consolidation when placed). Conventional grout is specified by (*1*) proportions or (*2*) strength requirements. Self-consolidating grout is specified by strength requirements.

1.2 The text of this specification references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this specification.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C5 Specification for Quicklime for Structural Purposes
C29/C29M Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C150/C150M Specification for Portland Cement
C207 Specification for Hydrated Lime for Masonry Purposes
C260/C260M Specification for Air-Entraining Admixtures for Concrete
C404 Specification for Aggregates for Masonry Grout
C494/C494M Specification for Chemical Admixtures for Concrete
C595/C595M Specification for Blended Hydraulic Cements
C618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C989/C989M Specification for Slag Cement for Use in Concrete and Mortars
C1019 Test Method for Sampling and Testing Grout for Masonry
C1157/C1157M Performance Specification for Hydraulic Cement
C1602/C1602M Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete
C1611/C1611M Test Method for Slump Flow of Self-Consolidating Concrete

3. Materials

3.1 Materials used as ingredients in grout shall conform to the requirements specified in 3.1.1 – 3.1.5.

3.1.1 *Cementitious Materials*—Cementitious materials shall conform to one of the following specifications:

3.1.1.1 *Portland Cement*—Type I, IA, II, IIA, III, and IIIA of Specification C150/C150M.

3.1.1.2 *Blended Cements*—Type IL, IS(<70), IP, IT(S<70), or blended cements with special properties designated by (A), (MS), or (HS), or a combination of (A) and (MS) or (HS), as appropriate, of Specification C595/C595M.

3.1.1.3 *Hydraulic Cements*—Types GU, HE, MS, or HS of Specification C1157/C1157M.

3.1.1.4 *Quicklime*—Specification C5.

3.1.1.5 *Hydrated Lime*—Type S of Specification C207.

3.1.1.6 *Coal Fly Ash or Raw Calcined Natural Pozzolan*—Specification C618. Grouts produced with blends of cement and fly ash or raw calcined natural pozzolan shall have the compressive strength specified (4.2.1.2 or 4.2.2.1).

3.1.1.7 *Granulated Blast Furnace Slag*—Specification C989/C989M. Grouts produced with blends of cement and

[1] This specification is under the jurisdiction of ASTM Committee C12 on Mortars and Grouts for Unit Masonry and is the direct responsibility of Subcommittee C12.05 on Grout & Grout Admixtures for Masonry.

Current edition approved Feb. 1, 2023. Published February 2023. Originally approved in 1961. Last previous edition approved in 2022 as C476 – 22. DOI: 10.1520/C0476-23.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

TABLE 1 Conventional Grout Proportions by Volume

Type	Parts by Volume of Cement[A]	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

[A]Includes Specification C150/C150M, C595/C595M, and C1157/C1157M cements as described in 3.1.1.

granulated blast furnace slag shall have the compressive strength specified (4.2.1.2 or 4.2.2.1).

3.1.2 *Aggregates*—Aggregates shall conform to Specification C404.

3.1.3 *Water*—Water shall conform to Specification C1602/C1602M.

NOTE 1—Specification C1602/C1602M allows potable water to be used without testing. Other sources of water may be used if the water meets the requirements of Specification C1602/C1602M.

3.1.4 *Admixtures*—Integral waterproofing compounds, accelerators, or other admixtures not mentioned definitely in the specification shall not be used in grout for use in reinforced masonry without approval from the specifier.

NOTE 2—The specifier is usually the Licensed Design Professional.

3.1.4.1 *Air-Entraining Admixtures*—Air-entraining admixtures shall conform to Specification C260/C260M.

NOTE 3—If the grout is to be used to bond masonry units to reinforcing bars, the use of air-entraining materials or air-entraining admixtures is not recommended.

3.1.4.2 *Admixtures for Ready-Mixed Grout Transported to the Job Site*—Retarding admixtures conforming to Specification C494/C494M, Type B or D are permitted in ready-mixed grout transported to the job site if the grout meets the compressive strength and slump requirements of 4.2.1.2.

3.1.4.3 *Admixtures for Self-consolidating Grout*—High-range water-reducing admixtures conforming to Specification C494/C494M, Type F or G, and viscosity-modifying admixtures conforming to Specification C494/C494M, Type S, are permitted in self-consolidating grout.

NOTE 4—High-range water-reducing admixtures are best suited to achieve the water reduction and slump flow values required for self-consolidating grout. Admixture suppliers should be consulted to ensure that the particular high-range water-reducing admixture is suitable for self-consolidating grout.

NOTE 5—Viscosity-modifying admixtures may be used to enhance the stability of self-consolidating grout. The C494/C494M requirements for Type S (specific performance) admixtures provide a means of determining that the viscosity-modifying admixture will not have adverse effects on fresh, hardened and durability properties of the grout. Admixture suppliers should be consulted to ensure that the particular viscosity-modifying admixture is suitable for self-consolidating grout.

3.1.4.4 *Antifreeze Compounds*—No antifreeze liquids, salts, or other substances shall be used in grout to lower the freezing point.

3.1.5 *Storage of Materials*—Cementitious materials and aggregates shall be stored in such a manner as to prevent deterioration or intrusion of foreign material or moisture. Any material that has become unsuitable for good construction shall not be used.

NOTE 6—If the grout is to be used to bond masonry units to reinforcing bars, the use of air-entraining materials or air-entraining admixtures is not recommended.

4. Grout Type and Proportions

4.1 *Type*—Grout type shall be specified as fine or coarse.

4.1.1 Fine grout shall be manufactured with fine aggregates.

4.1.2 Coarse grout shall be manufactured with a combination of coarse and fine aggregates.

NOTE 7—Building code provisions and grout space dimensions should be reviewed when selecting grout type or types.

4.2 *Proportions of Ingredients*—Proportions shall be determined as follows:

4.2.1 *Conventional Grout*—The grout shall be mixed to a slump of 8 to 11 in. (200 to 280 mm) as determined by Test Method C143/C143M. Proportions shall be determined by one of the following methods:

4.2.1.1 Requirements of Table 1.

4.2.1.2 *Specified Compressive Strength*—Proportions established by 28-day compressive strength tests in accordance with Test Method C1019 that equal or exceed the specified compressive strength. The grout shall have a minimum compressive strength of 2000 psi (14 MPa) at 28 days.

4.2.2 *Self-consolidating Grout*—Proportions shall be determined by the following method:

4.2.2.1 *Specified Compressive Strength*—Proportions established by 28-day compressive strength tests in accordance with Test Method C1019 that equal or exceed the specified compressive strength. The grout shall be mixed to a slump flow of 24 to 30 in. (610 to 760 mm) as determined by Test Method C1611/C1611M and shall have a Visual Stability Index (VSI) of not greater than 1 as determined by Appendix X1 of Test Method C1611/C1611M. The grout shall have a minimum compressive strength of 2000 psi (14 MPa) at 28 days.

NOTE 8—The value for T_{50} as described in Appendix X1.1 and Note X1.1 of Test Method C1611/C1611M is a property of self-consolidating concrete and can be used as an indicator of batch-to-batch quality, consistency and performance in-situ of self-consolidating grout. While there is no consensus as to the appropriate T_{50} for all self-consolidating grouts, average values from 1.5 to 4 sec, with variations of ±0.5 sec from the average value, determined for the particular self-consolidating grout, typically provide proper viscosity and indicate batch-to-batch consistency.

NOTE 9—Building code provisions should be reviewed when selecting the specified compressive strength of grout.

5. Measurement and Production

5.1 *Measurement of Materials*—Measure materials for grout such that the required proportions of the grout materials are controlled and accurately measured.

NOTE 10—When converting volume proportions to batch weights, use the following material bulk densities:

Material	Bulk Density, lb/ft³ (kg/m³)
Portland cement	94 (1505)
Blended cement	Obtain from bag or supplier
Other cementitious materials	Obtain from bag or supplier
Hydrated lime	40 (640)
Lime putty[A]	80 (1280)
Sand, damp and loose	80 (1280) of dry sand
Coarse aggregate	Use Test Method C29/C29M, Shoveling Method, to determine weight per cubic foot.

[A]All quicklime should be slaked in accordance with the manufacturer's directions. All quicklime putty, except pulverized quicklime putty, should be sieved through a No. 20 (850-µm) sieve and allowed to cool until it has reached a temperature of 80°F (26.7°C). Quicklime putty should weigh at least 80 lb/ft³ (281 kg/m³). Putty that weighs less than this may be used in the proportion specifications if the required quantity of extra putty is added to meet the minimum weight requirements.

5.2 *Production Methods*—Grout shall be produced using one of the following procedures:

5.2.1 *Grout Materials Mixed with Water at the Job Site:*

5.2.1.1 *Conventional Grout:*

(1) Individual cementitious materials and aggregates stored at the job site shall be mixed in a mechanical mixer for a minimum of 5 min with sufficient water to achieve the desired consistency.

(2) Individual ingredients transported to the job site in suitable compartments shall be mixed with water at the job site using continuous volumetric proportioning equipment to achieve the desired consistency. Mix with an auger of appropriate length to provide adequate mixing.

(3) Factory pre-blended grout materials delivered to the job site shall be mixed in a mechanical batch mixer for a minimum of 5 min or in a continuous mixer following mixer manufacturer's recommendation with sufficient water to achieve the desired consistency.

NOTE 11—Conventional grout may be hand-mixed on small jobs with written approval of the mixing procedure by the specifier.

5.2.1.2 *Self-consolidating Grout:*

(1) Individual ingredients transported to the job site as part of a self-consolidating grout manufacturer's system, shall be mixed at the job-site with water, per the manufacturer's recommendations, using continuous volumetric proportioning equipment to achieve the desired consistency. Mix with an auger of appropriate length to provide adequate mixing.

(2) Factory preblended grout materials delivered to the job site shall be mixed in a mechanical mixer with sufficient water, per the self-consolidating grout manufacturer's recommendation, to achieve the desired consistency.

(3) Job site proportioning and mixing of individual materials that are not part of a self-consolidating grout manufacturer's system shall not be permitted.

5.2.2 *Ready-Mixed Grout Transported to the Job Site:*

5.2.2.1 *Conventional Grout*—Grout shall arrive at the job site in a ready-mixed condition. Slump shall be adjusted as necessary, and grout shall be re-mixed at mixing speed for at least 1 min before discharging to achieve the desired consistency.

5.2.2.2 *Self-consolidating Grout*—Grout shall arrive at the job-site in a ready-mixed condition. The addition of water at the job site is permitted in accordance with the self-consolidating grout manufacturer's recommendations.

6. Keywords

6.1 aggregates; cement; compressive strength; grout; masonry; portland cement; proportions ; self-consolidating grout

SUMMARY OF CHANGES

Committee C12 has identified the location of selected changes to this standard since the last issue (C476 – 22) that may impact the use of this standard. (February 1, 2023)

(1) In subsections 3.1.1.6 and 3.1.1.7, deleted the sentence about "addition rates." Also, deleted the word "portland" to recognize that C595 and C1157 cements, like C150 cement, can be blended with fly ash, natural pozzolans, or slag.

Committee C12 has identified the location of selected changes to this standard since the last issue (C476 – 20) that may impact the use of this standard. (September 1, 2022)

(1) Revised subsections of 4.2.

3

C476 – 23

Designation: C143/C143M – 20

Standard Test Method for Slump of Hydraulic-Cement Concrete[1]

This standard is issued under the fixed designation C143/C143M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This test method covers determination of slump of hydraulic-cement concrete, both in the laboratory and in the field.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.3 The text of this standard refers to notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.[2])

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.60 on Testing Fresh Concrete.

Current edition approved June 1, 2020. Published July 2020. Originally approved in 1922. Last previous edition approved in 2015 as C143/C143M – 15a. DOI: 10.1520/C0143_C0143M-20.

[2] Section on Safety Precautions, Manual of Aggregate and Concrete Testing, *Annual Book of ASTM Standards*, Vol 04.02.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field

C138/C138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

C172/C172M Practice for Sampling Freshly Mixed Concrete

C173/C173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

C231/C231M Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

D638 Test Method for Tensile Properties of Plastics

3. Summary of Test Method

3.1 A sample of freshly mixed concrete is placed and compacted by rodding in a mold shaped as the frustum of a cone. The mold is raised, and the concrete allowed to subside. The vertical distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as the slump of the concrete.

4. Significance and Use

4.1 This test method is intended to provide the user with a procedure to determine slump of plastic hydraulic-cement concretes.

NOTE 1—This test method was originally developed to provide a technique to monitor the consistency of unhardened concrete. Under laboratory conditions, with strict control of all concrete materials, the slump is generally found to increase proportionally with the water content of a given concrete mixture, and thus to be inversely related to concrete strength. Under field conditions, however, such a strength relationship is

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

1

not clearly and consistently shown. Care should therefore be taken in relating slump results obtained under field conditions to strength.

4.2 This test method is considered applicable to plastic concrete having coarse aggregate up to 1½ in. [37.5 mm] in size. If the coarse aggregate is larger than 1½ in. [37.5 mm] in size, the test method is applicable when it is performed on the fraction of concrete passing a 1½-in. [37.5-mm] sieve, with the larger aggregate being removed in accordance with the section titled "Additional Procedure for Large Maximum Size Aggregate Concrete" in Practice C172/C172M.

4.3 This test method is not considered applicable to non-plastic and non-cohesive concrete.

NOTE 2—Concretes having slumps less than ½ in. [15 mm] may not be adequately plastic and concretes having slumps greater than about 9 in. [230 mm] may not be adequately cohesive for this test to have significance. Caution should be exercised in interpreting such results.

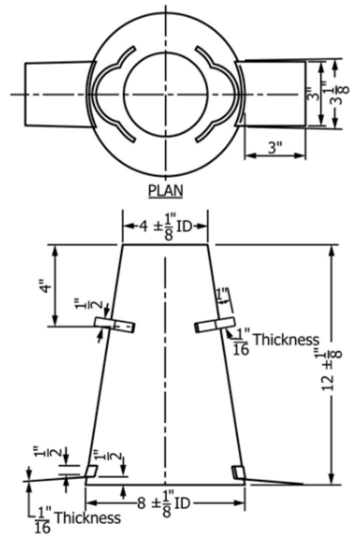
5. Apparatus

5.1 *Mold*—The test specimen shall be formed in a mold made of metal or plastic not readily attacked by the cement paste. The mold shall be sufficiently rigid to maintain the specified dimensions and tolerances during use, resistant to impact forces, and shall be non-absorbent. Metal molds shall have an average thickness of not less than 0.060 in. [1.5 mm] with no individual thickness measurement less than 0.045 in. [1.15 mm]. Plastic molds shall be ABS plastic or equivalent (Note 3) with a minimum average wall thickness of 0.125 in. [3 mm], with no individual thickness measurement less than 0.100 in. [2.5 mm]. The manufacturer or supplier shall certify the materials used in mold construction are in compliance with the requirements of this test method. The mold shall be in the form of the lateral surface of the frustum of a cone with the base 8 in. [200 mm] in diameter, the top 4 in. [100 mm] in diameter, and the height 12 in. [300 mm]. Individual diameters and heights shall be within ±⅛ in. [3 mm] of the prescribed dimensions. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles similar to those shown in Fig. 1. The mold shall be constructed without a seam. The interior of the mold shall be relatively smooth and free from projections. The mold shall be free from dents, deformation, or adhered mortar. A mold which clamps to a nonabsorbent base plate is acceptable instead of the one illustrated, provided the clamping arrangement is such that it can be fully released without movement of the mold and the base is large enough to contain all of the slumped concrete in an acceptable test.

NOTE 3—ABS (Acrylonitrile Butadiene Styrene) plastic exhibits the following minimum mechanical properties:

Tensile modulus of elasticity, at 73 °F [23 °C]	320 000 psi	[2206 MPa]
Tensile strength (Test Method D638)	5670 psi	[39 MPa]
Percent Elongation at Break, at 73 °F [23 °C]	40 %	

5.1.1 Check and record conformance to the mold's specified dimensions when it is purchased or first placed in service and at least annually thereafter. To measure the top diameter,



Dimensional Units

in.	1⁄16	⅛	½	1	3	3⅛	4	8	12
mm	[2]	[3]	[15]	[25]	[75]	[80]	[100]	[200]	[300]

FIG. 1 Mold for Slump Test

bottom diameter, and height, perform two measurements for each, approximately 90° apart, and record the results of each measurement. To verify mold thickness, perform two measurements approximately 180° apart at 1 ± ½ in. [25 ± 10 mm] from the top of the mold, two measurements approximately 180° apart at 1 ± ½ in. [25 ± 10 mm] from the bottom of the mold, and calculate the average of the four measurements.

5.2 *Tamping Rod*—A round, smooth, straight steel rod, with a ⅝ in. [16 mm] ± 1⁄16 in. [2 mm] diameter. The length of the tamping rod shall be at least 4 in. [100 mm] greater than the depth of the mold in which rodding is being performed, but not greater than 24 in. [600 mm] in overall length (Note 4). The rod shall have the tamping end or both ends rounded to a hemispherical tip of the same diameter as the rod.

NOTE 4—A rod length of 16 in. [400 mm] to 24 in. [600 mm] meets the requirements of the following: Practice C31/C31M, Test Method C138/C138M, Test Method C143/C143M, Test Method C173/C173M, and Test Method C231/C231M.

5.3 *Measuring Device*—A ruler, metal roll-up measuring tape, or similar rigid or semi-rigid length measuring instrument marked in increments of ¼ in. [5 mm] or smaller. The instrument length shall be at least 12 in. [300 mm].

5.4 *Scoop*—of a size large enough so each amount of concrete obtained from the sampling receptacle is representative and small enough so it is not spilled during placement in the mold.

6. Sample

6.1 The sample of concrete from which test specimens are made shall be representative of the entire batch. It shall be obtained in accordance with Practice C172/C172M.

7. Procedure

7.1 Dampen the mold and place it on a rigid, flat, level, moist, nonabsorbent surface, free of vibration, and that is large enough to contain all of the slumped concrete. It shall be held firmly in place during filling and perimeter cleaning by the operator standing on the two foot pieces or by a clamping arrangement to a base plate as described in 5.1. From the sample of concrete obtained in accordance with Section 6, immediately fill the mold in three layers, each approximately one third the volume of the mold (See Note 5). Place the concrete in the mold using the scoop described in 5.4. Move the scoop around the perimeter of the mold opening to ensure an even distribution of the concrete with minimal segregation.

NOTE 5—One third of the volume of the slump mold fills it to a depth of 2⅝ in. [70 mm]; two thirds of the volume fills it to a depth of 6⅛ in. [160 mm].

7.2 Rod each layer 25 times uniformly over the cross section with the rounded end of the rod. For the bottom layer, this will necessitate inclining the rod slightly and making approximately half of the strokes near the perimeter, and then progressing with vertical strokes spirally toward the center. Rod the bottom layer throughout its depth. For each upper layer, allow the rod to penetrate through the layer being rodded and into the layer below approximately 1 in. [25 mm].

7.3 In filling and rodding the top layer, heap the concrete above the mold before rodding is started. If the rodding operation results in subsidence of the concrete below the top edge of the mold, add additional concrete to keep an excess of concrete above the top of the mold at all times. After the top layer has been rodded, strike off the surface of the concrete by means of a screeding and rolling motion of the tamping rod. Continue to hold the mold down firmly and remove concrete from the area surrounding the base of the mold to preclude interference with the movement of slumping concrete. Remove the mold immediately from the concrete by raising it carefully in a vertical direction. Raise the mold a distance of 12 in. [300 mm] in 5 ± 2 s by a steady upward lift with no lateral or torsional motion. Complete the entire test from the start of the filling through removal of the mold without interruption and complete it within an elapsed time of 2½ min.

7.4 Immediately measure the slump by determining the vertical difference between the top of the mold and the displaced original center of the top surface of the specimen. If a decided falling away or shearing off of concrete from one side or portion of the mass occurs (Note 6), disregard the test and make a new test on another portion of the sample.

NOTE 6—If two consecutive tests on a sample of concrete show a falling away or shearing off of a portion of the concrete from the mass of the specimen, the concrete probably lacks necessary plasticity and cohesiveness for the slump test to be applicable.

8. Report

8.1 Report the slump in terms of inches [millimetres] to the nearest ¼ in. [5 mm] of subsidence of the specimen during the test.

9. Precision and Bias[4]

9.1 *Precision*—The estimates of precision for this test method are based upon results from tests conducted in Fayetteville, Arkansas by 15 technicians from 14 laboratories representing 3 states. All tests at 3 different slump ranges, from 1.0 in. [25 mm] to 6.5 in. [160 mm], were performed using one load of truck-mixed concrete. The concrete was delivered and tested at a low slump, with water then being added and mixed into the remaining concrete to independently produce moderate and finally high-slump concrete. The concrete mixture that used a No. 67 crushed limestone aggregate and a washed river sand, contained 500 lb of cementitious materials per cubic yard [297 kg of cementitious material per cubic metre]. The 500 lb [227 kg] were equally divided between a C150, Type I/II cement and a Class C fly ash. A double dosage of a chemical retarder was used in an attempt to minimize slump losses and maintain workability of the concrete. Concrete temperatures ranged from 86 to 93 °F [30 to 34 °C]. Slump losses averaged 0.68 in. [17 mm] during the 20 min required to perform a series of 6 tests at 1 slump range. Testing was performed alternately using metal and plastic molds, which were determined to produce comparable results. Precision data thus applies to both metal and plastic molds. A total of 270 slump tests were performed.

9.1.1 *Inch-Pound [SI]*—The data used to develop the precision statement were obtained using metric units (millimetres). The precision values shown in inch-pound units are conversions from the millimetre measurements, which were recorded to the nearest 1 mm.

9.1.2 *Measure of Variability*—The standard deviation was determined to be the most consistent measure of variability and was found to vary with the slump value.

9.1.3 *Single-Operator Precision*—The single-operator standard deviation represented by (1s) is shown in Table 1 by

[4] The test data used to develop this precision statement were based on tests performed in September 1997. Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:C09-1022. Contact ASTM Customer Service at service@astm.org.

TABLE 1 Precision

Slump and Type Index	Standard Deviation (1s)[A]		Acceptable Range of Two Results (d2s)[A]	
Single-Operator Precision:	in.	[mm]	in.	[mm]
Slump 1.2 in. [30 mm]	0.23	[6]	0.65	[17]
Slump 3.4 in. [85 mm]	0.38	[9]	1.07	[25]
Slump 6.5 in. [160 mm]	0.40	[10]	1.13	[28]
Multilaboratory Precision:				
Slump 1.2 in. [30 mm]	0.29	[7]	0.82	[20]
Slump 3.4 in. [85 mm]	0.39	[10]	1.10	[28]
Slump 6.5 in. [160 mm]	0.53	[13]	1.50	[37]

[A] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C670.

average slump values. The reported results for the replicate readings apply to tests conducted by the same operator performing successive tests, one immediately following the other. Acceptable results of two properly conducted tests by the same operator on the same material (Note 7) will not differ from each other by more than the (d2s) value of the last column of Table 1 for the appropriate slump value and single-operator precision.

9.1.4 *Multilaboratory Precision*—The multilaboratory standard deviation represented by (1s) is shown in Table 1 by average slump values. The reported results for the replicate readings apply to tests conducted by different operators from different laboratories performing tests less than 4 min apart. Therefore, acceptable results of two properly conducted slump tests on the same material (Note 7) by two different laboratories will not differ from each other by more than the (d2s) value of the last column of Table 1 for the appropriate slump value and multilaboratory precision.

NOTE 7—"Same materials," is used to mean freshly mixed concrete from one batch.

9.2 *Bias*—This test method has no bias since slump is defined only in terms of this test method.

10. Keywords

10.1 concrete; concrete slump; cone; consistency; plasticity; slump; workability

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue (C143/C143M – 15a) that may impact the use of this standard. (Approved June 1, 2020.)

(1) Revised 1.3.

Designation: C157/C157M – 17

Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete[1]

This standard is issued under the fixed designation C157/C157M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This test method covers the determination of the length changes that are produced by causes other than externally applied forces and temperature changes in hardened hydraulic-cement mortar and concrete specimens made in the laboratory and exposed to controlled conditions of temperature and moisture.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. An exception is with regard to sieve sizes and nominal size of aggregate, in which the SI values are the standard as stated in Specification E11. Within the text, the SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C125 Terminology Relating to Concrete and Concrete Aggregates
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C172 Practice for Sampling Freshly Mixed Concrete
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C305 Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
C490 Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
C596 Test Method for Drying Shrinkage of Mortar Containing Hydraulic Cement
C1437 Test Method for Flow of Hydraulic Cement Mortar
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

3. Terminology

3.1 *Definitions*—The terms used in this test method are defined in Terminology C125.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *length change, n*—an increase or decrease in the length of a test specimen that has been caused to change by any factor other than externally applied forces and temperature changes.

4. Significance and Use

4.1 Measurement of length change permits assessment of the potential for volumetric expansion or contraction of mortar or concrete due to various causes other than applied force or temperature change. This test method is particularly useful for comparative evaluation of this potential in different hydraulic-cement mortar or concrete mixtures.

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.68 on Volume Change.

Current edition approved Aug. 15, 2017. Published October 2017. Originally approved in 1940. Last previous edition approved in 2014 as C157/C157M – 08 (2014)$^{\varepsilon 1}$. DOI: 10.1520/C0157_C0157M-17.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

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C157/C157M – 17

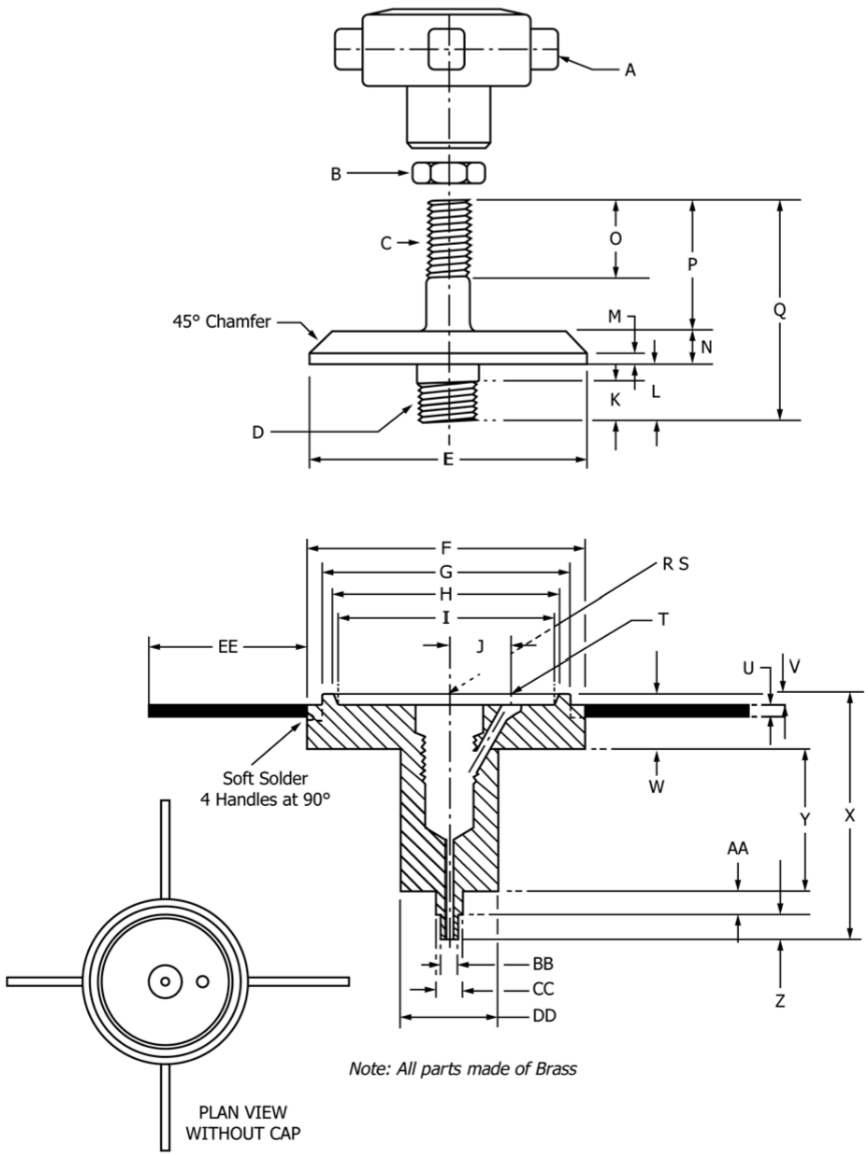

FIG. 1 Atmometer

4.2 This test method provides useful information for experimental purposes or for products that require testing under nonstandard mixing, placing, handling, or curing conditions, such as high product workability or different demolding times. Standard conditions are described in 5.4.1.

4.3 If conditions for mixing, curing, sampling, and storage other than specified in this test method are required, they shall be reported but are not to be considered as standard conditions of this test method. Nonstandard conditions and the reasons for departure from standard conditions shall be reported clearly and prominently with comparator values.

5. Apparatus

5.1 *Molds and Length Comparator*—The molds for casting test specimens and the length comparator for measuring length change shall conform to the requirements of Practice C490.

5.2 *Tamper*—The tamper shall be made of a nonabsorptive, nonabrasive material such as medium-hard rubber or seasoned oak wood rendered nonabsorptive by immersion for 15 min in paraffin at approximately 392 °F [200 °C], and shall have a cross section of ½ by 1.0 in. [13 by 25 mm] and a convenient length of about 6 in. [150 mm]. The tamping face of the tamper shall be flat and at right angles to the length of the tamper.

5.3 *Tamping Rod*—The tamping rod shall be a straight steel rod ⅜ in. [10 mm] in diameter and not less than 10 in. [250 mm] in length, having at least the tamping end rounded to a hemispherical tip of the same diameter.

5.4 *Drying Room and Controls*—A drying room with suitable racks shall be provided when storing specimens in air. The racks shall be designed for free circulation of air around specimens, except for necessary supports, and shall be so situated with respect to the nearest wall or other obstruction that air circulation is not restricted in the intervening space. The supports shall be horizontal and shall consist of two nonabsorptive members not deeper than 1 in. [25 mm] and having a bearing area of not more than ¼ in. [6 mm] in width. Conditioned air shall be circulated into and out of the room in a uniform manner so that the specified rate of evaporation is attained adjacent to all specimens.

5.4.1 The air in the room shall be maintained at a temperature of 73 ± 3 °F [23 ± 2 °C] and a relative humidity of 50 ± 4 %. The air movement past all specimens shall be such that the rate of evaporation is 77 ± 30-mL/24 h from an atmometer or 13 ± 5-mL/24 h from a 400-mL Griffin low-form beaker filled to ¾ in. [20 mm] from the top. The temperature and relative humidity of the air in the room shall be measured with either a sling or Assmann psychrometer at least twice each working day. The psychrometer shall comply with Test Method E337, except that thermometers having an overall length of 10 in. [250 mm] and marked in subdivisions of 0.5 °F [0.25 °C] are permitted. The room shall be equipped with a means of measuring and recording wet- and dry-bulb temperatures continuously. Correction factors as indicated by the sling or Assmann psychrometer shall be applied to the recorded data. The rate of evaporation within the room shall be determined daily by the use of the atmometer or by the loss of mass of water from a 400-mL Griffin low-form beaker filled initially to ¾ in. [20 mm] from the top.

5.5 *Atmometer*—The atmometer shall be constructed as shown in Fig. 1.

5.5.1 *Mounting*—Fig. 2 shows a suggested arrangement for operating the atmometer. Punch a central hole ½ in. [13 mm] in diameter in a filter paper, place it on the atmometer, and secure it in place while dry, by turning the torque handle only, until it just starts to slip. Mount the atmometer on a stand with the filter paper in a horizontal position. Mount a 100-mL glass graduate so that the 100-mL mark is from 1 to 3 in. [25 to 75 mm] below the level of the filter paper. Stopper the graduate so that entrance is provided for two short glass tubes not extending to the water level and one long tube extending to the bottom of the graduate. Connect the glass tubing leading from the bottom of the graduate to the inlet of the atmometer by means of clear plastic tubing.

5.5.2 *Operation*—Use clear plastic tubing to connect a squeeze bottle containing distilled or deionized water to one of the short glass tubes into the graduate. Force water into the graduate until it is about half full and then close the remaining glass tube into the graduate. Continue to force water through the graduate into the atmometer until the filter paper is saturated and there are no air bubbles in the system. Open the glass tube into the graduate and release pressure on the squeeze bottle gradually to avoid trapping air in the tube leading to the atmometer. Adjust the level of water in the graduate to approximately the 100-mL mark. If the atmometer is to be used under variable temperature conditions, disconnect the squeeze bottle after filling the graduate to avoid the possibility of additional water being forced into the graduate. Permit evaporation of water from the filter paper for 1 h before recording the time and initial reading of the graduate. It is not permitted to omit the waiting period during subsequent use of the atmometer provided the filter paper does not become dry. Change the filter paper whenever it shows signs of contamination but not less frequently than once every two weeks.

5.6 *Filter Paper*—The filter paper to be used with the atmometer shall be white with a smooth surface texture. It shall be 6 in. [152 mm] in diameter and 0.050 ± 0.003 in. [1.27 ± 0.08 mm] thick and shall have a cotton fiber content of not less than 75 weight %. The density shall be between 0.400 and 0.425 g/cm^3. The Mullen bursting strength shall not be less than 50 psi [345 kPa].

FIG. 1 Atmometer

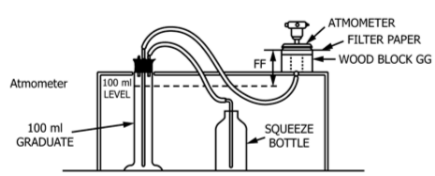

FIG. 2 Atmometer Assembly

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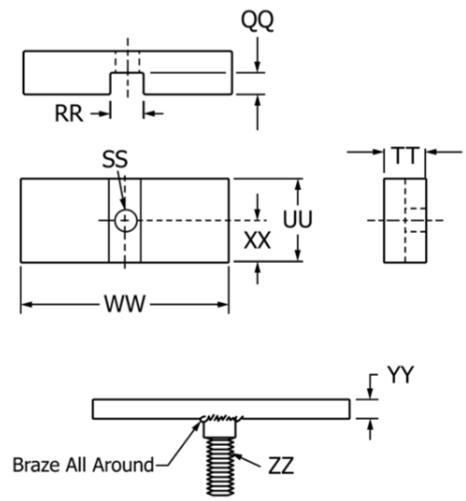
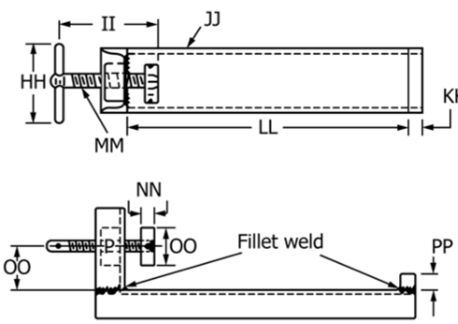


Instructions for Use—Remove the end and the outer side plates leaving the base, center side plate, and gage stud holders in place. Engage the machine screw in the drilled and tapped end of the center side plate. Turn the thumbscrew to loosen the bars.

FIG. 3 Device for Detaching 1-in. [25-mm] Square by 11¼-in. [285-mm] Bars from Center Side Plate of Double Molds



NOTE 1—Dimensions shown are appropriate for one design of mold for 3-in. [75-mm] square specimens. Change dimensions as required for other molds.

FIG. 4 Device for Demolding Specimens from Single Molds

NOTE 1—E and D filter paper No. 625[3] has been found suitable.

5.7 *Apparatus for Demolding Specimens*—It is useful to construct an apparatus for demolding specimens molded in double molds as detailed in Fig. 3 or to a different design that serves the same purpose. When this device is to be used, the center side plate of the double mold must be appropriately drilled and tapped to receive the 8-32 by ⅝ in. [4.5-0.74 IMC by 16 mm] machine screw of the demolding thumbscrew. Fig. 4 shows the details of a suitable apparatus for demolding specimens molded in single molds.

[3] The sole source of supply of the apparatus known to the committee at this time is Ahlstrom Filtration Co., Mt. Holly Springs, PA 17065. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

ASTM C157 FIGURES

Figure Dimensions	SI Units	Inch-Pound Units
A	Adjustable torque handle 1.4–1.7 Nm	Adjustable torque handle 12–15 in.lb
B	Jam nut 10–15 IMC	Jam nut ⅜-in.–16 NC
C	10-mm diameter 1.5 IMC Thd.	⅜-in. dia–16 NC Thd.
D	12-mm diameter 1.5 IMC Thd.	½-in. dia–20 NC Thd.
E	64-mm diameter	2.50-in. diameter
F	64-mm diameter	2.50-in. diameter
G	57-mm diameter	2.25-in. diameter
H	52-mm diameter	2.06-in. diameter
I	51-mm diameter	2.00-in. diameter
J	14 mm	0.56 in.
K	8 mm	0.31 in.
L	13 mm	0.50 in.
M	3 mm	0.125 in.
N	8 mm	0.31 in.
O	19 mm	0.75 in.
P	32 mm	1.25 in.
Q	53 mm	2.06 in.
R	1.5-mm drill through 11.5-mm C' drill	1⁄16-in. drill through 29⁄64-in. C' drill
	32-mm deep tap 12-mm 1.5-mm IMF Thd	1¼-in. deep tap ½-in.–20 Thd
S	19 mm deep 16 mm C' bore 6 mm deep	¾-in. deep ⅝-in. C' bore ¼ in. deep
T	5-mm drill 3-mm deep C' drill at 60° as shown through to center tapped hole	3⁄16-in. drill ⅛-in. deep C' drill at 60° as shown through to center tapped hole
U	3 mm	0.12 in. diameter
V	2 mm	0.09 in.
W	10 mm	0.40 in.
X	60 mm	2.36 in.
Y	35 mm	1.37 in.
Z	6 mm	0.25 in.
AA	6 mm	0.25 in.
BB	4 mm	0.15 in.
CC	6 mm	0.25 in.
DD	23 mm	0.87 in.
EE	38 mm	1.50 in.
FF	25 to 75 mm	1 to 3 in.
GG	35 mm high	1.37 in. high
HH	100 mm	4 in.
II	130 mm	5 in.
JJ	8 cm–6.1 kg/m channel	3 in.–4.1 lb/ft channel
KK	20 mm	¾ in.
LL	330 mm	13 in.
MM	14–2.0 IMC Thd.	½ in.–12 Thd.
NN	20 mm	¾ in.
OO	50 mm	2 in.
PP	20 mm	¾ in.
QQ	60 mm	¼ in.
RR	10 mm	⅜ in.
SS	Drill Cl. hole for 4.5–0.75 IMC machine screw	Drill Cl. hole for 8–32 in. machine screw
TT	13 mm	½ in.
UU	25 mm	1 in.
VV	30 mm	1-3⁄16 in.
WW	60 mm	2-⅜ in.
XX	12.5 mm	½ in.
YY	6-mm diameter steel rod	¼-in. diameter steel rod
ZZ	4.5–0.75 IMC × 16-mm machine screw	8–32 × ⅝-in. machine screw

6. Sampling

6.1 Take samples according to the applicable provisions of Practice C192/C192M from batches of hydraulic-cement mortar or concrete made in the laboratory (Note 2).

NOTE 2—When collecting samples in nonstandard conditions, such as field concrete, it is suggested that Practice C172 be followed. Field cast specimens can show up to twice as much drying shrinkage as laboratory cast specimens from the same materials and proportions.

7. Test Specimens

7.1 *Mortar*—The test specimen for mortar shall be a prism of 1-in. [25-mm] square cross-section and approximately 11¼ in. [285 mm] in length. Three specimens shall be prepared for each test condition.

7.2 *Concrete*—The test specimen for concrete, in which all of the aggregate passes a 2-in. [50-mm] sieve, shall be a prism of 4-in. [100-mm] square cross-section and approximately 11¼ in. [285 mm] long. However, a prism of 3-in. [75-mm] square cross-section shall be used if all of the aggregate passes a 1-in. sieve [25.0-mm]. Three specimens shall be prepared for each test condition. Since length change is capable of being influenced by the size of the specimen, specimens to be compared shall have the same dimensions, and any specification limit based upon this method shall be applied to a specified size of specimen.

8. Procedure for Mixing Mortars and Concrete

8.1 If the mortar or concrete to be tested is made in accordance with requirements other than those given in one of the following paragraphs, samples shall be taken and specimens molded as described in the sections on sampling and on molding specimens.

8.2 Bring all materials to a temperature between 65 and 75 °F [18 and 24 °C] before using to make mortar or concrete. Proportion solid materials by mass (that is, not by volume). It is permissible to batch water and liquid admixtures either by mass or by volume. For calculation of batch quantities, assume aggregates to be saturated and surface-dry; if they are not in this condition at the time of use, apply appropriate corrections, as necessary, to batch quantities to compensate for absorption or free moisture.

8.3 *Mortar*—Mix mortar in a mechanical mixer as described in Practice C305. The clearances between paddle and bowl specified in Practice C305 are suitable only for mortars made with fine aggregates that are finer than the 2.36 mm (No. 8) sieve. Mortars made with aggregates containing particles coarser than this sieve require special clearances or a different type of paddle to permit the mixer to operate freely and to avoid damage to the paddle and bowl. The sequence of mixing shall be in accordance with the applicable provisions of Practice C305. Determine the flow of the mortar in accordance with the applicable provisions of Test Method C1437, and use sufficient mixing water to produce a flow of 110 ± 5 %.

8.4 *Concrete*—Mix concrete in a suitable laboratory mixer in accordance with the applicable provisions of Practice C192/C192M. Determine the slump of the concrete using Test Method C143/C143M, and use sufficient mixing water to produce a slump of 3.5 ± ½ in. [90 ± 15 mm].

9. Procedure for Molding Specimens

9.1 *Mortar Specimens*—Place the mortar in the mold in two approximately equal layers. Compact each layer with the tamper. Work the mortar into the corners, around the gage studs, and along the surfaces of the mold with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, strike off the mortar flush with the top of the mold, and smooth the surface with a few strokes of a trowel. Immediately after completion of molding, loosen the device that holds the gage studs in position at each end of the mold in order to prevent any restraint of the gage studs during initial shrinkage of the specimen.

9.2 *Concrete Specimens*—Place the concrete in the mold in two approximately equal layers in accordance with the general instructions for placing concrete in specimens given in Practice C192/C192M. Consolidate each layer by rodding, except use external vibration if the slump is less than 3 in. [75 mm] in accordance with the instructions for consolidation of flexure test specimens given in Practice C192/C192M. The same method of consolidation is to be used for all specimens to be compared. In addition, as the top layer is being placed, work the concrete thoroughly around each gage stud with the fingers. The top layer shall slightly overfill the mold. After consolidation is complete, strike off the excess material with a straightedge. Immediately after completion of molding, loosen the device that holds the gage studs in position at each end of the mold in order to prevent any restraint of the gage studs before the test specimens are demolded.

10. Procedure for Curing of Specimens

10.1 Cure the test specimens in the molds in a moist cabinet or room in accordance with Specification C511. Protect specimens from dripping water.

10.2 Except for slowly-hardening specimens that would be damaged by handling, remove specimens from the molds at an age of 23½ ± ½ h after the addition of water to the cement during the mixing operation. In order to avoid damage during removal from the molds, especially in the case of certain slowly-hardening cements, keeping specimens in molds for more than 24 h is not prohibited. When this is found necessary the moist curing schedule shall be extended, but all specimens that are to be directly compared with each other shall be subjected to the same conditions of moist-curing and shall have their initial comparator reading made within ±½ h of the same age. It is permitted to use the demolding device to remove specimens without striking or jarring and with particular care not to exert pressure directly against the gage studs. The gage stud holder shall remain attached to the stud during this operation. Marks placed on the specimens for identification or positioning are only to be made by graphite applied either by a soft pencil or as a liquid that deposits essentially graphite without binder or made with waterproof indelible ink. Upon removal of the specimens from the molds, place them in lime-saturated water maintained at 73 ± 1 °F [23 ± 0.5 °C] for a minimum of 15 min in the case of 1-in. [25-mm] square cross-section specimens, and for a minimum of 30 min in the case of 3-in. [75-mm] or 4-in. [100-mm] square cross section specimens before being measured for length. This is to minimize variation in length due to variation in temperature. At an age of 24 ± ½ h after the addition of water to the cement during the mixing operation, remove the specimens from water storage one at a time, wipe with a damp cloth, and immediately take the initial comparator reading.

10.3 After the initial comparator reading, store the specimens in lime-saturated water at 73 ± 3 °F [23 ± 2 °C] until they have reached an age of 28 days, including the period in the molds. At the end of the curing period, take a second comparator reading after the specimens have been brought to a more closely controlled temperature as was done prior to the earlier reading and in the manner described above.

NOTE 3—To determine the drying shrinkage of concrete subjected to elevated temperature curing in the laboratory, a modification of the previous method is necessary. Where concrete is cured with elevated (non-autoclave) temperatures, the curing cycle for this test method shall be that to be used for the project structural members. The elevated temperature curing cycle consists of pre-steam, steam cure, and post-steam periods. To avoid measuring thermal volume change, after the molds are stripped, cool drying-shrinkage specimens at laboratory temperature until they reach equilibrium (approximately 6 h for 4 by 4 by 11-in. [100 by 100 by 280-mm] bars). Then place them in lime-saturated water prior to the initial reading (see 10.2).

11. Procedure for Storage of Specimens

11.1 After measurement at the end of the curing period, store the specimens as described in either of the following:

11.1.1 *Water Storage*—Immerse the specimens in lime-saturated water storage in accordance with Specification C511. Take comparator readings of each specimen when it has reached an age, including the curing period of 8, 16, 32, and 64 weeks. Make these readings immediately after the specimens have been subjected to storage in water at 73 ± 1 °F [23 ± 0.5 °C] for at least 15 min in the case of 1-in. [25-mm] specimens or 30 min in the case of 3-in. [75-mm] or 4-in. [100-mm] specimens.

11.1.2 *Air Storage*—Store the specimens in the drying room, so that the specimens have a clearance of at least 1 in. or 25 mm on all sides. Take comparator readings of each specimen after periods of air storage after curing of 4, 7, 14, and 28 days, and after 8, 16, 32, and 64 weeks. Preferably, take these readings in a room maintained at a relative humidity of 50 ± 4 % while the specimens are at a temperature of 73 ± 3 °F [23 ± 2 °C].

12. Procedure for Calculating Length Change

12.1 *Comparator Reading*—Read the comparator dial with the test specimen in the comparator; then read the comparator dial with the reference bar in the comparator. Calculate the difference between the two readings as described in Practice C490.

12.2 *Length Change*—Calculate the length change of any specimen at any age after the initial comparator reading as follows:

$$\Delta L_x = \frac{CRD - \text{initial } CRD}{G} \times 100 \quad (1)$$

where:

ΔL_x = length change of specimen at any age, %,
CRD = difference between the comparator reading of the specimen and the reference bar at any age, and
G = the gage length (10 in. [250 mm]) (see Note 4).

NOTE 4—In Practice C490, the comparator dial gage specified for use with 10-in. gage length specimens shall be graduated in fractions of an inch; the comparator dial gage specified for use with 250-mm gage length specimens shall be graduated in fractions of a millimetre.

13. Report

13.1 Report the following information:

13.1.1 Identification as mortar or concrete specimens, number of specimens for each condition, and date molded,

13.1.2 Source and identification of each material employed,

13.1.3 Type, maximum size, moisture condition, and grading of the aggregate,

13.1.4 Size of specimens,

13.1.5 Mortar or concrete mixture data at time of mixing, including flow or slump and temperature of mixture,

13.1.6 Description of consolidation of concrete, specifying whether rodding or external vibration was used,

13.1.7 Conditions and periods of moist curing prior and subsequent to removal of molds, if different from those specified,

13.1.8 Description of storage condition, including temperature and humidity, either by indicating whether the water or air storage was followed or by giving the details of any procedure not conforming to either of these conditions,

13.1.9 Total elapsed time of storage and total age of specimen, or total elapsed time of curing and storage if the same condition was used for both,

13.1.10 Length change data, reported as percent increase or decrease in linear dimension to the nearest 0.001 % of the gage length based on the initial measurement made at the time of removal from the molds, and

13.1.11 Any other pertinent information.

14. Precision and Bias

14.1 *Precision:*

14.1.1 When this test method was used for the purpose of determining drying shrinkage of mortar as affected by the choice of portland cement used in making it, the precision was found to be as reported in Test Method C596.

14.1.1.1 The following single-laboratory, multiple-operator precision applies to concrete specimens measured at 180 days.

14.1.1.2 For specimens stored in water, the standard deviation (1s) among specimens is 0.0045 %. When three replicate specimens are tested, the maximum range among them is not expected to exceed 0.0266 % in 95 % of the sets tested. When a test result represents the mean of three specimens, the 1s is 0.0026 %. The difference between two such means is not expected to exceed 0.0074 % in 95 % of such duplicate tests performed.

14.1.1.3 For specimens stored in air, the standard deviation (1s) among specimens is 0.0084 %. When three replicate specimens are tested, the maximum range among them is not expected to exceed 0.0496 % in 95 % of the sets tested. When a test result represents the mean of 3 specimens, the 1s is 0.0048 %. The difference between two such means is not expected to exceed 0.0137 % in 95 % of such duplicate tests performed.

NOTE 5—These precision values were calculated from data taken on specimens described on p. 47 of STP 205,[4] representing 193 concrete mixtures; two specimens made from each of three batches made on separate days, one of each two specimens stored in water, the other stored at nominal 50 % relative humidity.

14.2 *Bias*—No statement on bias is being made since there is no accepted reference material suitable for determining the bias of these procedures.

15. Keywords

15.1 length change; mortar concrete

[4] Mather, Bryant, "The Partial Replacement of Portland Cement in Concrete," *Cement and Concrete, ASTM STP 205*, ASTM, 1958.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue, C157/C157M – 08 (2014)$^{\varepsilon1}$, that may impact the use of this test method. (Approved Aug. 15, 2017.)

(1) Revised Sections 9.1, 9.2, and 10.2.

Committee C09 has identified the location of selected changes to this test method since the last issue, C157/C157M – 08$^{\varepsilon1}$, that may impact the use of this test method. (Approved Oct. 1, 2014.)

(1) Replaced Test Method C1347 with correct designation Test Method C1437 in Section 2 and 8.3.

C157/C157M – 17

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Reference Information

Ingredient Bulk Density Table

Ingredient	Bulk Density (lb/cu.ft.) Loose	Packed
Adipic Acid		45
Alfalfa Meal	14	22
Alfalfa Pellets	41	43
Alfalfa Seed	10	15
Almonds broken	27	30
Almonds whole shelled	28	30
Alum fine	45	50
Alum lumpy	50	60
Alumina	55	65
Alumina fines		35
Alumina sized or briquette		65
Aluminate gel		45
Aluminate hydroxide		
Aluminum chips, oily	7	15
Aluminum hydrate	13	20
Aluminum ore (see bauxite)		
Aluminum Oxide	60	120
Aluminum Silicate (andalusite)		49
Aluminum Sulfate	45	58
Ammonium Chloride, crystalline	45	52
Ammonium nitrate	45	62
Ammonium sulfate	45	58
Antimony Powder		
Apple pomace, dry		15
Arsenate of lead (see lead arsenate)		
Arsenic oxide (arsenolite)	100	120
Arsenic pulverized		30
Asbestos rock (ore)		81
Asbestos shredded	20	40
Ash, black ground		105
Ashes, coal, dry 1/2"	35	45
Ashes, coal, dry 3"	35	40
Ashes, coal, wet 3"	45	50
Ashes, fly (see fly ash)		
Asphalt, crushed 1/2"		45
Bagasse	7	10
Bakelite, fine	30	45
Baking powder	40	55
Baking soda (sodium bicarbonate)	40	55
Barite (barium sulfate) +1/2-3"	120	180
Barite powder	120	180
Barium carbonate		72
Bark, wood, refuse	10	20
Barley, fine, ground	24	38
Barley, malted		31
Barley, meal		28
Barley, whole	36	48
Basalt	80	105
Bauzite, dry, ground		68
Bauzite, crushed - 3"	75	85
Beans, castor, meal	35	40
Beans, castor, whole, shelled		36
Beans, navy, dry		48
Beans, navy, steeped		60
Bentonite, crude	34	40
Bentonite, 100-mesh	50	60
Benzene hexachloride		56
Bicarbonate of soda (see baking soda)		
Blood, dried	35	45
Blood, ground, dried		30
Bone ash (tricalcium phosphate)	40	50
Boneblack	20	25
Bonchar	27	40
Bonemeal	50	60
Bones, whole	35	50
Bones, crushed	35	50
Bones, ground		50
Borate of lime		60
Borax, fine	45	55
Borax, screening 1/2"	55	60
Borax, 1/2-2", lump	55	60
Borax, 2-3", lump	60	70
Boric acid, fine		55
Boron		75
Bran (rice-rye-wheat)	16	20
Braunite (manganese oxide)		120
Bread crumbs	20	25
Brewer's grain, spend, dry	14	30
Brewer's grain, spent, wet	55	60
Brick, ground, 1/8"	100	120
Bronze chips	30	50
Buckwheat	42	47
Calcine, flour	75	85
Calcium carbide	70	90
Calcium carbonate (see limestone)		

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Ingredient Bulk Density Table

Ingredient	Bulk Density (lb/cu.ft.) Loose	Packed
Cottonseed, meats, dry		40
Cottonseed, meats, rolled	35	40
Cracklings, crushed	40	50
Cryolite, dust	75	90
Cryolite, lumpy	90	110
Cullet, fine	80	120
Cullet, lumpy	80	120
Culm (see coal, anthracite)	80	120
Cupric sulphate (see copper sulphate		
Detergent (see soap detergent)		
Diatomaceous earth	11	17
Dicalcium phosphate	40	50
Disodium phosphate	25	31
Distiller's grain, spent, dry		30
Distiller's grain, wet	40	60
Dolomite, crushed	80	100
Dolomite, lumpy	90	100
Earth, loam, dry, loose		76
Ebonite, crushed	63	70
Egg powder		16
Epsom salts (magnesium sulphate)	40	50
Feldspar, ground	65	80
Feldspar, lumps	90	100
Feldspar, powder		100
Feldspar, screenings	75	80
Ferrous sulphide 1/2"	120	135
Ferrous sulphide 100M	105	120
Ferrous sulphate	50	75
Fish meal	35	40
Fish scrap	40	50
Flaxseed	43	45
Flaxseed cake (linseed cake)	48	50
Flaxseed mean (linseed meal)	25	45
Flour wheat	33	40
Flue dust, basic oxygen furnace	45	60
Flue dust, blast furnace	110	125
Flue dust, boiler H. dry	30	45
Fluorspar, fine (calcium fluoride)	80	100
Fluorspar, lumps	90	110
Flyash	30	45
Foundry sand, dry (see sand)		
Fuller's earth, dry, raw	30	40
Fuller's earth, oily spent	60	65
Fuller's earth, calcined		40
Galena (see lead sulfide)		

Bulk Density of Flyash

Ingredient	Bulk Density (lb/cu.ft.) Loose	Packed
Gelatine, granulated		32
Gilsonite		37
Glass, batch	80	100
Glue, ground		40
Glue, pearl		40
Glue, veg. powdered		40
Gluten, meal		40
Granite, fine	80	90
Grape pomace	15	20
Graphite flake		40
Graphite flour		28
Graphite ore	65	75
Guano, dry		70
Gypsum, calcined	55	60
Gypsum, calcined, powdered	60	80
Gypsum, raw - 1"	70	80
Hay, chopped	8	12
Hexanedioic acid (see adipic acid)		
Hominy, dry	35	50
Hops, spent, dry		35
Hops, spent, wet	50	55
Ice, crushed	35	45
Ice, flaked	40	45
Ice, cubes	33	35
Ice, shell	33	35
Ilmenite ore	140	160
Iron ore concentrate	120	180
Iron oxide pigment		25
Iron oxide millscale		75
Iron pyrites (see ferrous sulfide)		
Iron Sulphate (see ferrous sulfate)		
Iron Sulfide (see ferrous sulfide)		
Iron vitriol (see ferrous sulfate)		
Kafir (corn)	40	45
Kaolin clay		63
Kaolin clay-talc	42	56
Kryalith (see cryolite)		
Lactose		32
Lamp black (see carbon black)		
Lead arsenate		72
Lead arsenite		72
Lead carbonate	240	260
Lead ore - 1/8"	200	270
Lead ore - 1/2"	180	230
Lead oxide (red lead) 100 mesh	30	150
Lead oxide (red lead) 200 mesh	30	180
Lead sulfide - 100 mesh	240	260
Lignite (see coal lignite)		
Limanite, ore, brown		120

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Ingredient Bulk Density Table

Ingredient	Bulk Density (lb/cu.ft.)	
	Loose	Packed
Vermiculite, ore		80
Vetch		48
Walnut shells, crushed	35	45
Wheat	45	48
Wheat, cracked	40	45
Wheat, germ	18	28
White lead ,dry	75	100
Wood chips, screened	10	30
Wood flour	16	36
Wood shavings	8	16
Zinc, concentrate residue	75	78
Zinc oxide, heavy	30	35
Zinc oxide, light	10	15

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Statistical variation in the embodied carbon of concrete mixtures

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Abstract

This study presents a refined calculation of the embodied carbon of concrete mixtures *via* life cycle assessment (LCA) with an explicit focus on three innovations. First, probability distributions that represent process-related variability in the embodied carbon of are calculated using a variety of life cycle inventory data sources. Second, the traditional concrete LCA system boundary (*i.e.*, cra gate) is expanded to incorporate and analyze estimates of *in situ* carbon sequestration *via* concrete carbonation. Third, we analy impact of different transportation scenarios on the utility of using fly ash to reduce the embodied carbon of concrete. We use these data to heuristically determine the breakeven transportation distance for fly ash *via* trucking to be 2655 km for domestic sources of fly ash. However, when fly ash is imported from international sources, reductions to embodied carbon attributed to fly ash replacement can be negligible. The calculated breakeven maritime shipping distance for fly ash equals 15,110 km—beyond which, the anticipated embodied carbon reductions due to fly ash use in concrete are compromised due to transportation. The advancements described herein enable improved scenario-based decision-making for understanding, quantifying, and reducing the embodied carbon of concrete mixtures. In addition, the results highlight the importance of accounting for international transportation of fly ash in LCAs, especially given that domestic sources of quality fly ash are expected to continue to decline and imports are expected to increase in many parts of the world over the next few decades.

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Keywords

Concrete; Life cycle assessment; Embodied carbon; Variability; Fly ash; Transportation

1. Introduction

The manufacturing of cement, the most carbon-intensive component of concrete, contributes about 7% of global carbon dioxide CO_2 emissions (International Energy Agency IEA, 2018). Due to the ubiquity of concrete and its contribution to anthropogenic CO_2 emissions, a large body of literature exists that aims to understand, quantify, and subsequently reduce the embodied carbon of concrete. Multiple comparative life cycle assessment (LCAs) of alternative concretes or concrete materials that compare the embodied carbon of different concrete mixtures have been published (Vieira et al., 2016; Anastasiou et al., 2017; Weil et al., 2009; De Schepper et al., 2014; Celik et al., 2015; Jiang et al., 2014; Serres et al., 2016; Gursel et al., 2016; Colangelo et al., 2018; Van den Heede and De Belie, 2012). In addition to a myriad of LCAs that report environmental impacts of a functional unit volume of concrete (*e.g.*, 1 m^3, 1 yd^3),

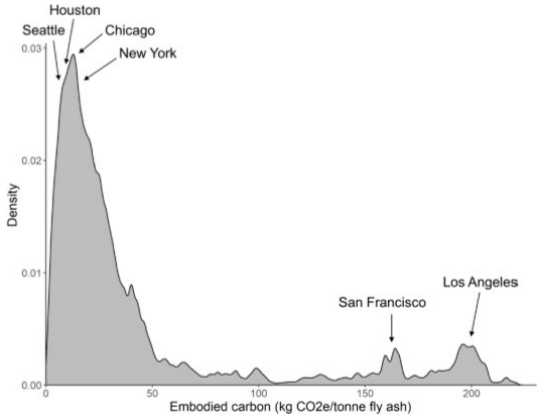

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Fig.8. Density function of embodied carbon due to domestic fly ash transportation.

5.2. Comparison of possible fly ash transportation assumptions

In past years, fly ash utilization rates in the US have been low (less than 50% until 2016 (Adams, 2018)), making the *most-local-fly-ash* assumption reasonable. In recent years, however, fly ash utilization has increased, and the price of domestic fly ash has followed suit. Consequently, longer distance transportation and imports of international fly ash have started to become more common. Thus, as fly ash utilization continues to increase, it is likely that the *most-local-fly-ash* assumption will not be accurate moving into the future.

In order to compare the impact of the fly ash transportation, we use various transportation scenarios to compare the *most-local-fly-ash* assumption from the previous section in terms of their embodied carbon impact. As domestic fly ash sources are depleted, the distance to sources of fly ash will increase. Thus, an alternate scenario to consider is the *breakeven trucking* distance. This scenario represents the maximum distance by which it is still beneficial in terms of total embodied carbon to transport fly ash *via* semi-truck. Another alternate scenario is to determine the embodied carbon impact from importing fly ash from international fly ash suppliers. Since China, India, and Turkey are the three largest fly ash exporters (Ash Around the World, 2018), we select an example scenario in which fly ash is transported *via* cargo ship from Shenzhen, China to New York, NY. Additional trucking is temporarily ignored for this scenario for the sake of generalization. Furthermore, we temporarily use average embodied carbon values for each impact category in order to compare possible fly ash transportation assumptions.

Fig.9 illustrates the difference in total embodied carbon for each of these scenarios due to transportation differences. In addition, each scenario is compared to the baseline mixture that contains no fly ash in order to determine the relative embodied carbon savings. The dotted regions represent the reduction in life cycle embodied carbon due to carbonation, which is slightly greater for mixtures without fly ash. Therefore, the net embodied carbon is represented by the solid outline. Under the *most-local-fly-ash* assumption, there is a significant benefit to fly ash replacement in terms of embodied carbon. For the *breakeven-trucking* assumption, any reduction in embodied carbon is eliminated when fly ash is transported more than 2655 km by truck. Finally, for the *international shipping* assumption, the benefit of using fly ash is eliminated due to the long-distance maritime shipping (and additional trucking will further increase the embodied carbon of this mixture). In fact, the mixture with 20% fly ash has an embodied carbon value 4% higher than the mixture without fly ash.

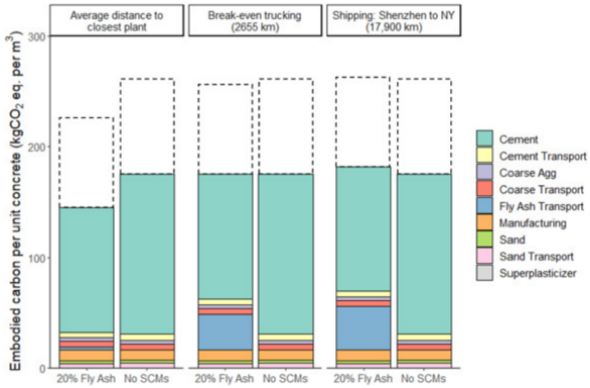

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Fig. 9. Comparison of embodied carbon for different transportation scenarios and fly ash replacements, using average embodied carbon values for each impact category. The solid outline represents total embodied carbon inclusive of carbonation.

This analysis illustrates the criticality of using the appropriate assumption for fly ash transportation to capture holistic greenhouse gas emissions. In other words, determining the correct fly ash transportation assumption (*i.e.*, mode and distance) is key in assessing the benefit of using fly ash in order to reduce the embodied carbon of concrete mixtures.

5.2.1. International fly ash shipments

Lastly, as international imports of fly ash become more common, it is important to consider how different maritime shipping distances will impact the benefit of fly ash utilization. Utilization of SCMs, like fly ash, in simplified LCAs are often characterized as being able to substantially reduce the embodied carbon of concrete. Such conclusions are due to the fact that many studies assume a relatively low, deterministic value for fly ash transportation distance (Purnell and Black, 2012), (Vargas and Halog, 2015), (Jones et al., 2011).

However, this analysis has shown that the benefit of using fly ash to reduce concrete embodied carbon is highly dependent on the method of transportation and distance. Fig. 10 can be used as a design tool to determine the quantity of embodied carbon savings that have been "spent" by fly ash transport, which is shown as a percent of possible CO_2 savings if there is no transportation. Thus, the 100% dashed line is the "breakeven" line at which all embodied carbon savings from cement replacement have been eliminated because of fly ash transportation. In other words, for transportation scenarios above this dashed line, there is a higher value of embodied carbon for that mixture than for one that uses no fly ash. To use the graph, the gray contours represent maritime shipping distances in kilometers for international shipments of fly ash; the contour line can be followed along its increasing slope for the additional trucking that may occur from transporting fly ash to the appropriate location. At this point on the graph, the percentage of embodied carbon savings that have been "spent" on fly ash transportation can be obtained.

Literature Review on the Use of Harvested Coal Ash as a Supplementary Cementitious Material with Recommendations for ASTM C618

Doug Hooton, University of Toronto
And
Michael Thomas, University of New Brunswick

October 15, 2021

1.0 Introduction

1.1 Coal fired power generation in USA

Coal-fired power generation in the USA and in North America is diminishing. In some states, the amount of coal power production is diminishing rapidly and has already resulted in fly ash shortages and shortages are expected to become increasingly more severe. As a result, the availability of fly ash is also diminishing and this will result in a significant problem for concrete producers in terms of concrete durability and in reducing concrete's carbon footprint. Without other significant commercially available sources of supplementary cementitious materials (SCMs) in some parts of the USA, there is an urgent need to broaden the ASTM C618 specification to address the growing practice of using harvested fly ash stored in properly evaluated landfills or ponds. Landfilled fly ash is typically moistened with 10 to 15 % water and compacted in layers. When full, landfills are typically capped with soil or clay. Ponded fly ash is first slurried with water and then pumped into lagoons, which are later dewatered. In some cases, fly ash is stored separately as a monofill, but in many cases, bottom ash may be comingled with the fly ash in the coal ash landfill or lagoon.

In some cases, the landfilled ash was originally deemed non-suitable for uses as a SCM due to high LOI, but in most cases, the fly ash was of good quality, but there was insufficient market for it at the time of production. Also, with recent environmental regulations governing coal power plants requiring low NOx burners, SOx scrubbing, or mercury capture, fly ash in older landfills may be of better quality for use as a SCM than currently produced fly ash.

It should be noted that harvested fly ashes would almost always need to be processed before use to reduce moisture content and to ensure that the ash is of appropriate fineness.

This paper provides a review of the literature on the properties of harvested fly ashes as well as bottom ashes and co-mingled ashes when used as a ASTM C618 compliant SCM or in blended hydraulic cements in ASTM C595. Current requirements in standard specifications are also reviewed.

1.2 Coal Ash Properties and Utilization

The principal by-products produced from the burning of pulverized coal in a coal-fired electrical generation station are fly ash (FA), bottom ash (BA) and in some cases, flue-gas desulfurization

Table 18b. Comparison of Fly Ash Specifications-2 (JCI 2016)

Table 5-2 Comparison of specified fly ash between Japan and other countries *1

Name of country				UK			AUSTRALIA				CHINA								REPUBLIC of KOREA	
Standards				BS3892			AS3582.1				GB1596								KSL5405	
Year of establishment				1993			1998b				2005								2009	
Types				PART I	PART II		Special*2	Normal			I		II		III		For cement mixture		Type 1	Type2
					A	B		Fine	Medium	Coarse	F	C	F	C	F	C	F	C		
Chemical components	Silicon Oxide		%	---	---	---	---	---	---	---	---						---		---	
	Silicon Dioxide		%	---	---	---	---	---	---	---	---						---		≧45	
	Sulfur Trioxide		%	2≧	2.5≧		---	3≧			3≧						3.5≧		---	
	Moisture content		%	0.5≧	0.5≧		---	1≧			1≧						1≧		1≧	
	Ignition loss		%	6≧	7≧	12≧	4≧	4≧	5≧	5≧	5≧		8≧		15≧		8≧		3≧	5≧
	Chloride ion		%	0.1≧	---		---	---			---						---		---	
	Free Calcium Oxide		%	10≧	---		---	---			1≧	4≧	1≧	4≧	1≧	4≧	1≧	4≧	---	
	Active Calcium Oxide		%	---	---		---	---			---						---		---	
	Magnesium Oxide		%	---	4≧		---				---						---		---	
	Total of Silicon Dioxide + Ferric Oxide + Aluminum Oxide		%	---	---		---	---			---						---		---	
	Alkali content		%	---	---		---	---			---						---		---	
Physical properties	Density		g/cm³	≧2	---		---	---			---						---		≧1.95	
	Fineness	Specific surface area	cm²/g	---	---		---	---			---						---		≧4500	≧3000
		Percentage retained over 45μm sieve	%	12≧	30≧& ≧12.5	60≧& ≧30	25≧	25≧	35≧	50≧	12≧		25≧		45≧		---		10≧	40≧
	Activation index	7 days	%	≧80 (8days)	---			---			---						---		---	
		28 days	%	---	---			---			---						≧70		≧90	≧80
		91 days	%	---	---			---			---								≧100	≧90
	Ratio of flow value (Ratio of water content)		%	(95≧)	---			---			(95≧)		(105≧)		(115≧)		---		105≧	95≧
	Soundness	Expansion ratio by autoclave	%	---	---						---						---		---	
Other specified items				For structural concrete	For grout		*2: Relative strength > 105%				---						---		---	

*1: Japan Concrete Institute: Reduction in Shrinkage Cracks and Improvement of Durability in View of Admixture, Committee Report of the JCI, pp. 89-99, 2010

4. Summary on Potential Inclusion of Harvested, Comingled and Bottom Ash in ASTM C618

This review of the literature and recent data indicates that coal fly ash and bottom ash from the same furnace will be very similar in chemical composition, and both will contain amorphous phases that react as a pozzolan. The main difference is that unground bottom ash particles are coarser than fly ash. So, with adequate grinding, comingled ash should be as acceptable for use as fly ash. Data from several studies showed that if not ground to a sufficient fineness, the water demand of mortars made with 100 % unground bottom ash is increased and strength activity is reduced; however, when sufficiently ground there is no increase in water demand and strength is equal to that of fly ash from the same source. Bottom ashes are also able to improve chloride penetration resistance, mitigate ASR and improve sulfate resistance similar to fly ashes from the same source. Therefore, harvested coal ashes, whether from fly ash, bottom ash, or comingled ash, should also be suitable for use.

This does not change when the coal ash is harvested from landfills or lagoons except the harvested ash will likely need to be dried and that potentially injurious levels of contaminants must be removed or eliminated through selective mining. Therefore, it is concluded that harvested ash should be suitable for use as a supplementary cementitious material in concrete under the current fly ash designations in ASTM C618, subject to the following provisions:

5/20/23, 12:25 PM Tonnage in Shipping - Gross Tonnage, Net Tonnage & Displacement

BLOG

Articles on Logistics 04 May 2022

Tonnage in Shipping - Gross Tonnage, Net Tonnage & Displacement

The article has been reviewed and edited by Alexandra Ortiz

The process of shipping involves numerous calculations, combinations, and approvals. Tonnage is one such metric that helps ensure safety and smoothness in shipping.

definitions of tonnage and how they are measured

What is Tonnage in Shipping?

Tonnage in shipping is the carrying capacity of the ship measured in terms of volume or weight. The word 'tonnage' is derived from the practice of levying dues on ships. These dues were collected based on 'tons' that a vessel could accommodate.

In the past, the tonnage was calculated based on the ship's internal volume. But today, the measurement procedure has changed to a system where the cargo's weight is considered the unit of measurement. Ton is the standard unit of measure for this capacity.

Although the technical definition of tonnage has changed several times, it is usually expressed in terms of weight or volume. To sum up, tonnage in shipping is the total number of tons registered or the total carrying capacity of the ship.

Who Issues International Tonnage Certificates in Shipping?

Manning regulations, registration fees, port dues calculation, and safety rules are devised based on the tonnage of ships. All ships should have an International Tonnage Certificate (ITC), which is issued by the flag states in consultation with the Tonnage Measurement of Ships 1969 and the International Maritime Organization (IMO) International Convention.

The vessel's certificate society carries out the required calculations before delivery. It also issues the certificate on behalf of the flag state. Even though the certification has an expiry date, it has to be amended in the case of changes in the vessel's framework.

What is Tonnage Tax in Shipping?

Tonnage tax is a taxing method levied on shipping companies instead of conventional corporate taxation. The tax amount is usually less than the traditional government taxes and, therefore, is often considered the leading maritime subsidies offered by the government in recent times. The tax is levied based c tonnage value of the entire fleet of vessels under the operation of a single enterprise.

Another upside of this taxation mechanism is that it is not dependent on the profit of the company volume of the total shipments, making it easy and convenient for shipping companies and authoriti calculate tax.

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https://www.dripcapital.com/en-us/resources/blog/tonnage-in-shipping 1/4

BLOG

How is Tonnage Calculated?

Before understanding how shipping tonnage is calculated, it is vital to understand the meaning of two crucial terms.

Gross Tonnage

Gross tonnage is the total size of the vessel, expressed in terms of volume, of the enclosed area within the ship, right from the keel to the funnel.

The following formula allows for an easy method for calculating the gross tonnage:

differences in gross and net tonnage when it comes to shipping freighters

Gross tonnage (GT) = K1 x V

Where, k1 = 0.2 + 0.02LogV , and V + total number of enclosed spaces in cubic meters.

Net Tonnage

Net tonnage is the molded volume of the entire cargo space of the ship. It only considers the volume of the vessel that can be used for loading the cargo. The net tonnage is expected to be somewhere around 30% less than its gross tonnage.

The following formula facilitates the method of calculating the net tonnage:

Net tonnage = k2 x Vc x (4d/3D)^2 + k3 x (N1 + N2/10)

Where, K2 = 02. + 0.2LogVc

Vc = Entire volume of cargo spaces in cubic meters K3 = 1.25 x (GT + 10000)/10,000 d = Summer load line draught in meters D = Molded depth amid ships in meters N1 + Number of passengers in the cabin with as many as eight berths N2 = Number of other passengers N1 + N2 = The total Number of passengers that the ship is allowed to carry according to its passenger certificate. If N1 + N2 is less than 13, N1 and N2 should be taken as zero. GT = Gross tonnage of the vessel

Here are a few other considerations to keep in mind:

- The factor (4d/3D)^2 should be greater than unity.
- The term K2Vc(4d/3D)^2 should not be taken as less than a quarter of the gross tonnage.
- Net tonnage should not be less than 0.30 x gross tonnage.

Tonnage of Container Ship

The tonnage of container ships is measured by applying the same formulas as discussed above. Or a large container ship of 20,250 TEU would measure around 1,445ft x 195ft compared to 1,304 ft for the other ship classes. It would have an estimated capacity of approximately 220,000 tons.

What Does Deadweight Tonnage Mean in Shipping?

Deadweight tonnage is the measurement of a ship's contents, including cargo, fuel, passengers, crew, food, and water. It is measured in long tons of 2,240 pounds (approximately 1,016 Kilograms).

BLOG

board is called the displacement tonnage. It is measured in metric tones.

It is the actual weight of the ship since a floating object displaces the same amount of water as its weight. On the other hand, the light displacement of a ship is the amount of water it displaces with no passengers, crew, cargo, fuel, water, or food onboard.

FAQs On Tonnage In Shipping

1. What is tonnage length in shipping/container?

Tonnage length refers to 96% of the total distance covered by a ship's waterline at 85% of the least molded depth when measured from the top of the keel. It can also be the size from the front side of the stem to the axis of the rudder stock on the waterline if that is greater.

2. What is the net tonnage of a ship?

The net tonnage of a ship is a metric that determines the actual capacity of cargo that the vessel can carry.

3. How big is a 100-ton ship?

Depending on its construction and primary uses, a 100-ton ship can be around 65 feet or more.

Alexandra Ortiz

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U.S. Energy Information Administration

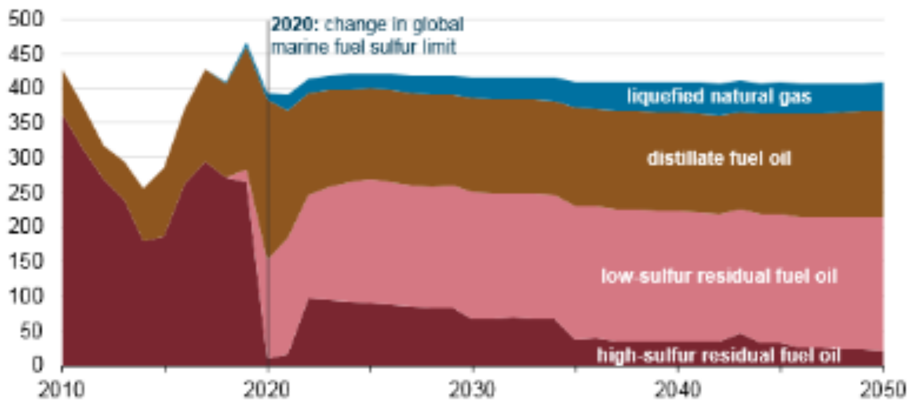
Skip to sub-navigation

Today in Energy

February 4, 2019

More stringent marine sulfur limits mean changes for U.S. refiners and ocean vessels

U.S. ocean-going marine vessel fuel consumption in AEO2019 Reference case
thousand barrels of oil equivalent per day



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2019*

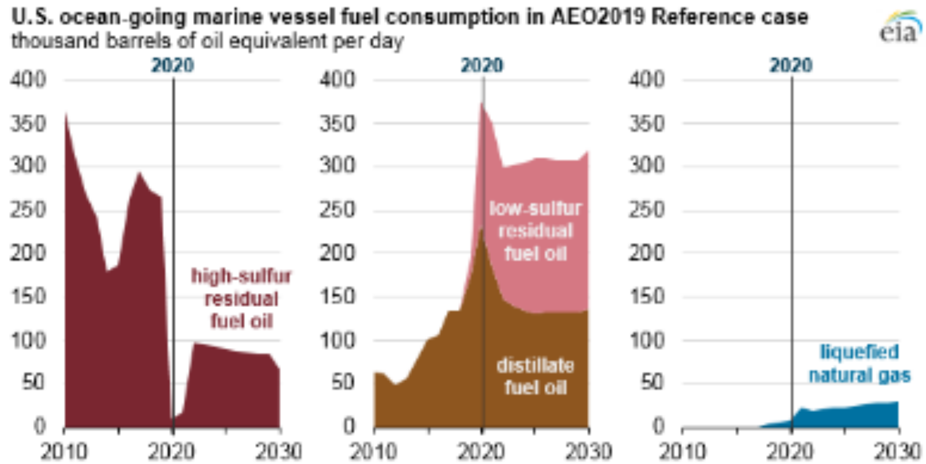
this talks about the current and new regulations on marine fuel

The implementation of new regulations affecting marine fuel specifications will have implications for crude oil and petroleum product markets over the coming decade. Previous *Today in Energy* articles described these regulations and the short-term implications for refining margins through 2020. Today's article discusses the longer-term implications of the market changes projected in EIA's recently released *Annual Energy Outlook 2019*, as the response to these regulations will likely involve changes to ships, marine fuels, refining, and some infrastructure in the next six to eight years.

The International Marine Organization's (IMO) new regulations limit the sulfur content in marine fuels used by ocean-going vessels in international waters to 0.5% by weight starting in January 2020, a reduction from the previous global limit of 3.5% established in 2012. This lower limit will change the way bunker fuel (the fuel mix consumed by large ocean-going vessels) is consumed in the United States, which, according to AEO2019, accounted for about 411,000 barrels per day (b/d) in 2018. This volume represents 3% of total transportation energy use and 1% of total U.S. petroleum and liquid fuel use.

This upcoming change will have wide-scale repercussions for the shipping industry and refineries in the United States and worldwide. Globally, marine vessels account for a critical part of the global economy, moving more than 80% of global trade by volume and more than 70% by value. Marine vessels also consume about 4 million b/d of petroleum, 4% of total global oil consumption. As outlined in a previous *Today in Energy* article, there are three main pathways for meeting the more stringent sulfur content regulations:

- Installing scrubbers to remove pollutants from ships' exhaust so ships can continue consuming high-sulfur residual fuel oil
- Switching to lower-sulfur residual fuel oil or blending with distillate fuel oil to achieve lower-sulfur fuel mixes
- Switching from petroleum-based fuels to other fuels such as liquefied natural gas (Because this option involves retrofitting costs, it is likely to be constrained to new builds.)



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2019*

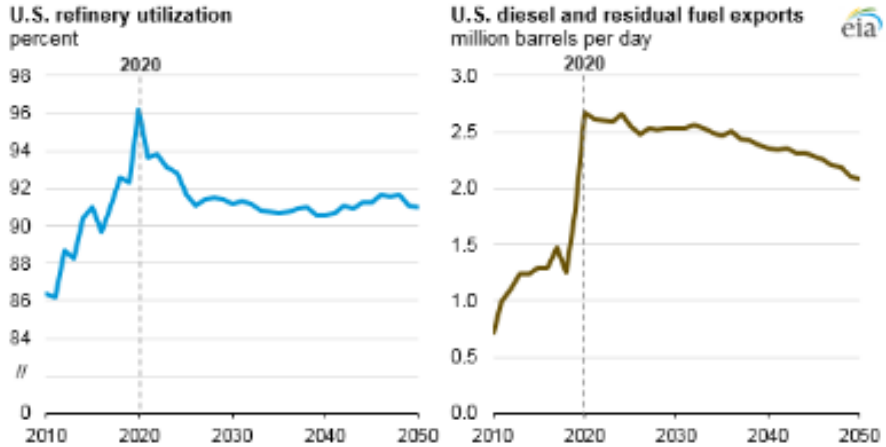
Residual oil currently accounts for the largest component of bunker fuel. EIA projects that the share of high-sulfur residual fuel oil consumed by U.S. ocean-going marine vessels will quickly drop in the near term, from 58% in 2019 to 3% in 2020 because few ships currently have scrubbers installed or will have them installed by 2020. As some ships install scrubbers that allow them to consume higher-sulfur fuels, EIA expects the residual fuel share to rebound partially to 24% in 2022.

Switching to lower-sulfur residual fuel oil or higher distillate blends is likely to be a more common compliance option for U.S. vessels. EIA projects that the share of low-sulfur residual fuel oil consumed in the U.S. bunker fuel market will increase from close to zero in 2018 to 38% in 2020. Similarly, EIA projects that the need to use distillate in lower-sulfur bunker fuels will increase distillate's share of U.S. bunkering demand from 36% in 2019 to 57% in 2020. After 2020, these fuels continue to account for relatively large shares of the fuels used in marine vessels.

EIA expects the use of liquefied natural gas (LNG) in U.S. marine bunkering to be limited in the next five years, reflecting the limited infrastructure available to accommodate LNG bunkering at U.S. ports. As infrastructure adapts, LNG's share of U.S. bunkering grows to 7% in 2030 and to 10% in 2050.

Similar to the January *Short-Term Energy Outlook* (STEO) forecast, the AEO2019 Reference case projects that the U.S. refining sector will respond to the projected lower demand for high-sulfur residual fuel oils as well as increased demand for low-sulfur fuels in two ways: increasing refinery utilization and switching to lower-cost inputs.

Much of U.S. refining capacity, especially on the U.S. Gulf Coast, has downstream units that upgrade residual oils into more valuable and lower-sulfur products. These complex units can process heavier and higher-sulfur crude oils that yield large quantities of residual oils. U.S. refinery utilization increases to 96% in 2020 and remains between 90% and 92% after 2026 through 2050 in the AEO2019 Reference case as these refineries aim to convert heavy, high-sulfur crude oil and residual fuel oil into lower-sulfur fuels. This change results in both increased imports of unfinished oils and increased exports of lower-sulfur diesel and residual fuels to supply the global market.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2019*

The *This Week in Petroleum* article published on January 30, 2019, provides additional analysis of the market implications for refinery margins through 2050. Diesel fuel is expected to have higher refinery margins than other petroleum products such as motor gasoline and jet fuel once the IMO regulations are in effect.

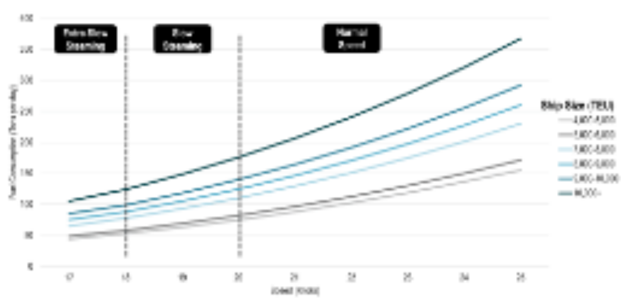
Principal contributors: Corrina Ricker, Nicholas Chase, Mark Schipper, Mason Hamilton

The Geography of Transport Systems

The spatial organization of transportation and mobility

Fuel Consumption by Containership Size and Speed

fuel usage as a function of ship size and speed



Fuel Consumption by Containership Size and Speed

Source: adapted from Notteboom, T. and P. Carriou (2009) "Fuel surcharge practices of container shipping lines: Is it about cost recovery or revenue making?". Proceedings of the 2009 International Association of Maritime Economists (IAME) Conference, June, Copenhagen, Denmark.

Fuel consumption by a containership is mostly a function of ship size and cruising speed, which

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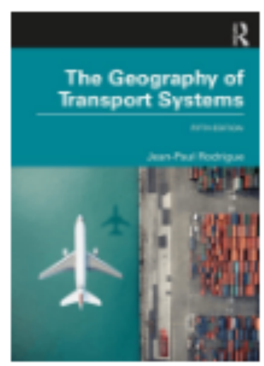

The Geography of Transport Systems
FIFTH EDITION
Jean-Paul Rodrigue (2020), New York: Routledge, 456

follows an exponential function above 14 knots. For instance, while a containership of around 8,000 TEU would consume about 225 tons of bunker fuel per day at 24 knots. At 21 knots, this consumption drops to about 150 tons per day, a 33% decline. While shipping lines would prefer consuming the least amount of fuel by adopting lower speeds, this advantage must be mitigated with longer shipping times as well as assigning more ships on a pendulum service to maintain the same port call frequency. The main ship speed classes are:

this is the usage of the ship in question

following are the typical travel speeds

- **Normal** (20-25 knots; 37.0 – 46.3 km/hr). Represents the optimal cruising speed a containership and its engine have been designed to travel at. It also reflects the hydrodynamic limits of the hull to perform within acceptable fuel consumption levels. Most containerships are designed to travel at speeds around 24 knots.
- **Slow steaming** (18-20 knots; 33.3 – 37.0 km/hr). Running ship engines below capacity to save fuel consumption but at the expense of an additional travel time, particularly over long distances (compounding effect). This is likely to become the dominant operational speed as more than 50% of the global container shipping capacity operated under such conditions as of 2011.
- **Extra slow steaming** (15-18 knots; 27.8 – 33.3 km/hr). Also known as super slow steaming or economical speed. A substantial decline in

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speed to achieve a minimal fuel consumption level while still maintaining a commercial service. It can be applied to specific short-distance routes.

- **Minimal cost** (12-15 knots; 22.2 – 27.8 km/hr). The lowest speed technically possible, since lower speeds do not lead to any significant additional fuel economy. However, the level of service is commercially unacceptable, so it is unlikely that maritime shipping companies would adopt such speeds.

The practice of slow steaming emerged during the financial crisis of 2008-2009 as international trade and the demand for containerized shipping plummeted at the same time as new capacity ordered during boom years was coming online. As a response, maritime shipping companies adopted slow steaming and even extra slow steaming services on several of their pendulum routes. It enabled them to accommodate additional ships with a similar frequency of port calls. It was expected that as growth resumed and traffic picked up, maritime shipping companies would return to normal cruising speeds. However, in an environment of higher fossil fuel prices, maritime shipping companies are opting for slow steaming for cost-cutting purposes but using the environmental agenda to justify them further. Slow steaming practices have become the new normal to which users must adapt.

Slow steaming also involves adapting engines designed for a specific optimal speed of around 22-25 knots, implying that they run at around 80% of full power capacity for that speed. Adopting slow steaming requires the "de-rating" of the main engine to the new speed and new power level (around 70%), which involves the timing of fuel injection, adjusting exhaust valves, and exchanging other mechanical components in the engine. The ongoing practice of slow steaming is likely to impact supply chain management, maritime routes, and the use of transshipment hubs. For instance, slow steaming has different impacts depending on the type of trade involved. Low-value goods in containers, such as waste products (a dominant American export), are less impacted than the retail trade, which is more time-sensitive.

streaming is at 80% full power capacity of the engine

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Understanding The Differences Between Diesel Fuel Grades

By SeoFebruary 28, 2018No Comments

Diesel fuel has far more uses than regular gasoline because its components contain more energy per gallon. Experts rate diesel fuel more favorably than gasoline because the vapors rarely explode or ignite during usage. As of 2007, the Environmental Protection Agency (EPA) has mandated that all highway diesel fuels sold in the United States must meet specifications before the general public has access to it. Doing this is thought to help reduce the emissions that come from diesel powered vehicles.

Diesel is commercially available in many grades, but the differences between each grade do not affect the uses of the fuel. The grades have their own benefits and disadvantages and must give up certain characteristics in order to gain different features. For example, #1 grade diesel fuel has lower energy components then it's counterpart, #2 grade diesel fuel. #2 will also form into a gel in cold weather environments. The following can help you understand the differences between #1 and #2 varieties, as well as winterized and AG diesel.

#1 diesel fuel

#1 grade products have less energy components and are more expensive that their chief counterpart, #2 grade products. However, it rarely has problems in cold weather conditions, which is completely the opposite of #2 grade. This is because paraffin (a type of wax) has been removed from the chemical mix. The absence of this chemical allows it to remain in liquid form during the winter months.

definitions of #2 Diesel fuel and pros and cons of the usage. explains why it is used

#2 diesel fuel

#2 grade diesel fuel is the most readily available at most gas stations throughout the world. This chemical compound holds the highest amount of energy components and lubricant properties in one mixture and offers the best fuel performance available on the market today. Most scientists agree that #2 grade diesel fuel will protect injection pumps, seals, and other important engine parts.

Typically, #2 is less expensive than #1 because it doesn't require the same depth of refinement to produce for sale. The downside to #2 diesel is its tendency to transform into a thickened gel when the temperature drops. This often leads to hard starts and other complications during winter.

Winterized diesel fuel

Winterized diesel fuel is a combination of #1 and #2 fuels that, when blended together, holds a higher concentration of #1 grade diesel fuel. These fuels are used during the months when it becomes too cold to use #2 grade.

The combination of both grades of fuel should contain enough energy components and lubricant properties to reduce the chance of the chemical mix gelling in colder temperatures. Typically, the fuel economy drops slightly during the winter months because the demand for it is less than at other times of the year.

Using #1 grade diesel fuel in the winter should never cause any immediate concerns. However, prolonged use in engines that are specifically-designed for #2 grade may reduce engine life span over a long period of time. #1 and #2 grade fuels can be mixed at the same time. This means you don't have to worry if #1 grade is only available during the winter months.

Blog / Semi Trailer Dimensions, Length & What Can You Haul

Semi Trailer Dimensions, Length & What Can You Haul

TIPS

The Transwest Team
Feb 01, 2021

Share

While the term semi trailer is used by the public to refer to the common box trailer-tractor cab combinations seen driving down the highway, the reality is that this word encompasses a vast array of trailer types. For those who work in the industry, understanding the specifics of semi trailer dimensions and what each style of trailer can haul is key.

The following guide will walk through common trailer styles, their dimensions, including length, width, and height, as well as what capacity loads they can haul. Additionally, a few key regulations around semi trailer dimensions and load weights will be outlined, helping operators understand when specialized permits are required by state.

DIMENSIONS, LENGTH, AND FREIGHT WEIGHT BY TRAILER TYPE

Not all semi trailers are designed with the same use case in mind. For this reason, their dimensions and load weight vary based on what they are intended to haul. The following list curated from Paige Ltd. quickly breaks down some of the most common semi trailer dimensions.

FLATBED TRAILERS

Flatbed trailers can haul a maximum weight of 48,000 pounds. However, tri-axle trailers can haul up to 65,000 pounds, making them ideal for heavy cargo.

Common dimensions for flatbeds are as follows:

Length- 48 ft – 53 ft

Width- 8.5 ft

Height- 8.5 ft

DRY VANS

Dry vans boast a freight weight of 42,000 pounds to 45,000 pounds, depending on the specific van. A dry van with a tri-axle, however, can haul up to 63,000 pounds.

Common dry van dimensions are as follows:

Length- 48 ft – 53 ft

Width- 8.2 ft

Height- 8 ft

REFRIGERATED TRAILERS

Refrigerated trailers are designed to transport temperature-sensitive items, such as produce, dairy goods, and other foods. Their max freight weight is 42,000 to 45,000 pounds for a standard refrigerated trailer and 63,000 pounds for a tri-axle.

Common refrigerated trailer dimensions are as follows:

Length- 48 ft – 53 ft

Width- 8.2 ft

Height- 8 ft

LOWBOYS

Lowboys offer a maximum cargo weight of 40,000 pounds for a standard two-axle trailer. You can add on an additional trailer and cargo combination weight of up to 95,000 pounds depending on the number of axles used.

Common lowboy trailer dimensions are as follows:

Dimensions used in Analysis

Length- 24 ft – 29.6 ft

Well Height- 18 in – 24 in

Width- 8.5 ft

Legal Freight Height- 11.5 ft – 12 ft

Legal Overall Load Height- 14 ft

STEP DECKS

Step decks are designed with a maximum freight weight of 48,000 pounds for a standard trailer. A tri-axle offers a freight weight of 65,000 pounds.

Common step deck trailer dimensions are as follows:

Length- 48 ft – 53 ft

Width- 8.5 ft

Height- 10 ft

FEDERAL REGULATIONS FOR INTERSTATES

When operating a semi trailer, it's not just about how the trailer itself was designed to carry loads or how large a manufacturer can create the trailer to be. More importantly, it is also about following the legal regulations surrounding trailers. According to the U.S. Department of Transportation Federal Highway Administration, the following are the mandated maximum weights for the National System of Interstate and Defense Highways:

- 80,000 pounds gross vehicle weight
- 20,000 pounds single axle weight
- 34,000 pounds tandem axle weight

Interestingly, a key consideration for semi operators is the spacing of axles. The Federal Highway Administration looks to protect bridges by calculating the number and spacing of axles carrying the load weight. This is called a bridge formula and is applied to commercial vehicles to ensure compliance.

The specific formula from the Federal Highway Administration is as follows:

W=500(LN/N-1 + 12N + 36); where W=overall gross weight on any group of 2 or more consecutive axles to the nearest 500 pounds. L=distance in feet between the extreme of any group of 2 or more consecutive axles, and N=number of axles in the group under consideration

When it comes to hauling oversize loads, the federal government is not the one to issue permits to operators. Instead, this is handled on a state-by-state basis.

REGULATIONS BY STATE

When hauling cargo across state lines, it is critical to understand what semi trailer dimensions are allowed and what requires additional permitting.

Different states have their own regulations for oversize load permitting, which can make the matter even more complex. The following information gathered from Coast to Coast Trucking Permits extensive state-by-state list helps to highlight the exceptions of which trailer operators should be aware.

SINGLE AXLE RESTRICTIONS

The majority of states allow you to haul 20,000 pounds on a single axle trailer without a permit. However, this is not the case for every state. The following list breaks down states that do not adhere to this regulation, including information about what necessitates permitting. (Note: in some cases, state's will allow for heavier loads than the standard):

Connecticut: Single axle trailers are allowed up to 22,400 pounds if spaced over 6 feet apart

Florida: Single axle trailers are allowed up to 22,000 pounds

Georgia: Single axle trailers are allowed up to 20,340 pounds

Idaho: Single axle trailers are allowed up to 24,000 pounds

Iowa: Single axle trailers are allowed up to 20,000 pounds with pneumatic tires and 14,000 pounds with solid rubber tires

Louisiana: Single axle trailers are allowed up to 20,000 pounds on designated highways, and 22,000 pounds on all other roads

Massachusetts: Single axle trailers are allowed up to 24,000 pounds

New Hampshire: Single axle trailers are allowed up to 20,000 pounds or 22,400 pounds if the gross weight is under 73,280 pounds

New Jersey: Single axle trailers are allowed up to 22,400 pounds

New Mexico: Single axle trailers are allowed up to 21,600 pounds

New York: Single axle trailers are allowed up to 22,400 pounds

Rhode Island: Single axle trailers are allowed up to 22,400 pounds

GROSS WEIGHT RESTRICTIONS

When it comes to hauling heavy cargo, gross weight is an important consideration beyond just cargo weight. The majority of states follow the regulation of 80,000 pounds gross weight. However, certain states have different allowances as outlined below (Note: in some cases, states will allow for heavier gross weight allowances than the standard):

80,000 lb gross weight limit

Alaska: Not specified

Colorado: Gross weight equals 80,000 pounds on interstates and 84,000 pounds on non-interstate roads

Kansas: Gross weight equals 80,000 pounds on interstates and 85,500 pounds on other routes

Maine: Gross weight equals 80,000 pounds on interstates and 100,000 pounds on other highways

New Mexico: Gross weight equals 86,400 pounds

Oklahoma: Gross weight equals 80,000 pounds on state and interstate highways and 90,000 pounds on other roads

Washington: Gross weight equals 105,500 pounds

West Virginia: Gross weight equals 80,000 pounds except on local roads with a gross weight limit of 65,000 pounds

Wyoming: Gross weight on interstates is 117,000 pounds, while the gross weight on other routes is 80,000 pounds

WIDTH RESTRICTIONS

In general, states abide by the width restriction of 8 feet 6 inches. However, in some states there are exceptions based on the road or load type:

Arkansas: 8'6", except for manufactured homes which have an 8′ limit

Florida: 8'6", except for on roads less than 12′ wide which have an 8' limit

Kentucky: 8'6" on national networks and 8' on other highways

Michigan: 8'6" on designated highways and 8' on non-designated highways

New York: 8'6" except on highways with a pavement width of less than 10′ in which case it is an 8′ limit

West Virginia: 8'6" except on local service routes less than 10′ wide where an 8′ limit is in place

HEIGHT RESTRICTIONS

The majority of states allow for a standard height of 13 feet and 6 inches before necessitating special permitting. The following are states that operate with different regulations:

Alaska: 15'

Arizona: 14'

California hight restriction

California: 14'

Colorado: 13'

Idaho: 14'

Kansas: 14'

Louisiana: 14' on designated highways and 13'6" on all other roads

Maine: 14', 13'6" on Maine turnpike

Missouri: 13'6", 14' on designated highways

Montana: 14'

Nebraska: 14'6"

Nevada: 14'

New Mexico: 14'

North Dakota: 14'

Oregon: 14'

South Dakota: 14'

Texas: Height 14'

Utah: 14'

Washington: 14'

Wyoming: 14'

YOUR PARTNER FOR SEMI TRAILER ACQUISITION

When it comes to choosing a semi trailer, the right dimensions and load capabilities are critical to getting the job at hand done. Whether you are hauling goods around town or across the country, at Transwest, we are here to help you acquire the trailers you need to get the job done. Talk to our knowledgeable staff today about purchasing additional trailers for your fleet.

CR Minerals

TEPHRA POZZOLAN

Tephra® RFA

CR Minerals offers a unique remediated fly ash, Tephra® RFA, to serve the ready-mix market, DOT infrastructure projects, concrete products manufacturers and the oil & gas industries as a high performance pozzolan that meets or exceeds all of the criteria for ASTM C618 Class F fly ash. Tephra RFA is a blend of fly ash from coal combustion beneficiated with naturally occurring pozzolans from ancient volcanic geological events. The beneficiation process results in a very reactive Class F pozzolan which significantly enhances the strength of concrete, relative to other Class F pozzolans, and outperforms 100% OPC mix designs in long term compressive strength. This newly available Class F fly ash will mitigate the most reactive aggregates (per ASTM C1260/1567) and successfully protect against sulfate attack (per ASTM C1012).

More Environmentally Sound

Tephra RFA pozzolan removes coal combustion fly ash from the waste stream that has been destined for the landfills or settling ponds and beneficiates this waste fly ash with the purest of natural pozzolans to meet ASTM C618 Class F fly ash specifications. In concrete production, Tephra RFA can typically remove and replace cement as a supplementary cementitious material (SCM) at levels of 15-40% by weight in a concrete mix design, resulting in optimized concrete mixes and a reduction in greenhouse gas emissions.

Sustainability and Reliable Sourcing

Due to more stringent environmental regulations to control emissions from coal combustion facilities over the past two decades, along with public mandates and market economics to utilize alternatives to coal for energy production, reliable supplies of Class F fly ash are diminishing. This creates localized, seasonal shortages of supply as well as a long-term issue with supply and costly importing of fly ash from other geographic areas. This market reality has affected concrete

specifiers, concrete producers and contractors in their efforts to protect our concrete infrastructure without a reliable and available Class F pozzolan. Tephra RFA helps fill this critical shortage with our local sourcing of manufactured and blended raw materials to produce a reliable and predictable supply of material that meets the requirements of Class F fly ash.

Quality Control and Consistency

Tephra® RFA is rigorously tested for consistency of particle size, chemistry, and performance. The result is a product that minimizes water demand variability as it effects concrete slump, ensures a stable air void matrix that reduces variability in plastic and hardened air contents of concrete, and maximizes strength gain creating opportunities for mix design optimization over other competitive pozzolans.

Pozzolan Benefits:

benefits of the use of pozzolans in the mix of grout and concrete

Enhances Compressive Strength

The pozzolanic reaction between CRM Tephra® RFA and excess calcium hydroxide in the concrete pore solution begins almost immediately, providing for concrete compressive strengths that are similar to 100% OPC concretes at 7 days and exceed OPC concrete strength at 28 days. At replacement levels of 15~40%, the RFA concrete strength will continue to increase well past 28 days, giving an ultimate long-term strength advantage over an OPC-only concrete of 10% to 35%, depending on mix design.

Comparison Data - Tephra RFA

Sample	Cem TI/II %	Replacement %	w/c	7d	7d - SAI	28d	28d - SAI
Cement T I/II	100	0	0.48	5967	100	7210	100
Tephra RFA	80	20	0.48	5256	88	7698	107
Tephra NP	80	20	0.48	4892	91	7207	100
F Ash #1	80	20	0.48	4677	87	6335	88
F Ash #2	80	20	0.48	4389	84	6434	89
F Ash #3	80	20	0.48	4663	87	6663	92
C Ash	80	20	0.48	5382	100	6885	95

Mitigates Alkali Silica Reaction (ASR)

CR Minerals' Tephra® RFA has a higher surface area than other Class F fly ashes which results in a very reactive pozzolan. The RFA readily reacts with calcium hydroxide as it

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CR Minerals

TEPHRA POZZOLAN

becomes available in the cement paste and incorporates the liquid phase alkali into additional calcium silicate hydrate binder (C-S-H). By densifying the cement paste and removing calcium hydroxide as a potentially deleterious agent in the concrete, the prospect of ASR is drastically mitigated.

Resists Sulfate Attack
CRM Tephra® RFA pozzolan will react with the calcium hydroxide to form additional C-S-H, thereby removing or mitigating the opportunity for the naturally occurring sulfates in certain soils to react and damage the concrete. Additionally, the RFA pozzolan will decrease the concrete's permeability, thus restricting the ingress of sulfate infused moisture.

Reduces Permeability and Efflorescence
The leaching of calcium hydroxide produced by the hydration of Portland cement can be a significant contributor to the formation of efflorescence and internal porosity in all Portland cement-based concrete. Tephra® RFA pozzolan can effectively mitigate this by reacting with the calcium hydroxide to form stabilizing and strength enhancing C-S-H before it migrates to the surface of the concrete.

Protects Steel Reinforcement / Resists Chloride Attack
Concrete made with Tephra® RFA pozzolan in the mix design can protect steel reinforcement by creating a more densely packed concrete matrix which then resists the ingress of chloride containing liquids and other chemicals into the concrete. When 15-40% of cement is replaced with Tephra® RFA, it will react with the free calcium hydroxide and form a denser, less permeable paste, providing greater resistance to the ingress of harmful chemicals into the concrete matrix

Reduces Heat of Hydration
Experiments show that replacing 15-40% Portland cement (OPC) with Tephra® RFA pozzolan can reduce the expansion and heat of hydration by as much as 20~40%. Less heat is produced when pozzolan reacts with the available calcium hydroxide. Tephra® RFA pozzolan not only decreases the overall heat generated by cement hydration, it also delays the time of peak temperature. The 'heat of hydration' of a Tephra® RFA pozzolan–OPC cement mixture is extended longer and lower to form a more moderate curve than the 'heat of hydration' curve for OPC itself.

Water Demand
Fly ashes generally provide a lower water demand than cement while natural pozzolans generally provide a water demand that is similar to or slightly higher than Portland cement. The water demand for a concrete mixture incorporating Tephra® RFA typically ranges from 98-102% of the Portland cement control.

Time of Set Characteristics
As with most pozzolans, the initial time of set compared to 100% OPC can be delayed as the percentage replacement increases, special consideration should be given when selecting the usage of water reducing admixtures. Lignosulfonate or blends of lignosulfonate-based admixtures tend to contribute to slower set times in conjunction with use of Tephra® RFA. Polycarboxylate Ether based water reducers (PCE's)typically can reduce undesirable side effects of delayed time of set when used with Tephra® RFA. Most admixture suppliers have a family of PCE-based water reducers that are available for use. Consult with your admixture supplier for assistance on selection and use of an appropriate water reducer for your application.

Cold Weather Concrete Practices
The American Concrete Institute under ACI 306 defines that concrete will be exposed to cold weather when the following conditions exist for a period of 3 consecutive days: The average daily air temperature is less than 40F (5°C) and/or the air temperature is not greater than 50F (10°C) for more than one-half of any 24-hour period. During these periods, be conscious of the use Tephra® RFA in conjunction with a lignosulfonate-based water reducer as mentioned earlier. As normal, monitor concrete production temperatures and concrete temperatures in place during cold weather. Dosage rates or type of water reducing admixture may need to be adjusted for cold weather concrete and concrete accelerating admixtures may be needed. Consult with your admixture supplier. Refer to ACI document 306R-16 "Guide to Cold Weather Concreting" Refer to NRMCA Concrete In Practice (CIP) #27 Cold Weather Concreting.

Technical Information Summary

Bulk Density used in this analysis

Bulk Density: 47-50 lbs./c.f.
Specific Gravity: 2.38-2.45
Passing 325 mesh screen: 90%+
Water demand: 98~102% of cement control
Strength Activity Index (SAI): 85~95% @ 7 days; 100~117% @ 28 days, depending on mix design
ASTM C618 Class F: Meets or exceeds all Class F specifications
AASHTO M295 Class F: Meets or exceeds all Class F specifications
ASTM C1012: Meets Class 3 exposure requirements at 6, 12, and 18 months
ASTM C1260/C1567: Acceptable mitigation at 14 days and 28 days of a highly reactive aggregate which is known to cause .6~.7% mortar bar expansion in only 14 days; in the same mix design, using Tephra® RFA at 25% replacement of the cement, the 14 day (.02) and 28 day (.07) expansion results are well below the acceptable limit per C1567.

Additional Information at www.CRMinerals.com
To place an order or obtain additional information, please contact CR Minerals at719-239-7869

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GSA

Sustainable Design

Contacts
Vendor Support

Sustainable design seeks to reduce negative impacts on the environment, and the health and comfort of building occupants, thereby improving building performance. The basic objectives of sustainability are to reduce consumption of non-renewable resources, minimize waste, and create healthy, productive environments.

Sustainable design principles include the ability to:

- optimize site potential;
- minimize non-renewable energy consumption;
- use environmentally preferable products;
- protect and conserve water;
- enhance indoor environmental quality; and
- optimize operational and maintenance practices.

Utilizing a sustainable design philosophy encourages decisions at each phase of the design process that will reduce negative impacts on the environment and the health of the occupants, without compromising the bottom line. It is an integrated, holistic approach that encourages compromise and tradeoffs. Such an integrated approach positively impacts all phases of a building's life-cycle, including design, construction, operation and decommissioning. For more information, contact Lance Davis (lance.davis@gsa.gov) or pbsvend@gsa.gov

GSA and Sustainable Design

The Energy Policy Act (EPAct) of 2005 addressed U.S. energy production, and included building-related provisions to "design new federal buildings to achieve energy efficiency at least 30 percent better than ASHRAE 90.1 standards, where life-cycle cost effective." Designers and energy modelers are encouraged to use GSA's 2020 Energy Use Target Guidance [PDF - 642 KB] to establish energy usage intensity targets. That guidance includes flowcharts to help simplify compliance with the energy efficiency laws, executive orders, and P100 sections applicable to GSA construction and modernization projects.

In 2006, 19 federal agencies signed a Memorandum of Understanding committing to "federal leadership in the design, construction, and operation of High-Performance Sustainable Buildings." This interagency memo yielded what is now called the Guiding Principles for Sustainable Federal Buildings, and charged agencies to optimize buildings' performance while maximizing assets' life-cycle value. Federal agencies are required by Executive Order to make annual progress toward 100% portfolio compliance with the Guiding Principles.

The Energy Independence and Security Act (EISA) of 2007 [PDF] established additional environmental management goals. New GSA buildings and major renovations must meet requirements including: reducing fossil-fuel-generated energy consumption by 80 percent by 2020 and by 100 percent by 2030, managing water from 95th percentile rain events onsite, and applying sustainable design principles to siting, design, and construction.

EPA United States Environmental Protection Agency

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Frequent Questions about the 2015 Coal Ash Disposal Rule

***** NOTE *****

Amendments to the 2015 final rule have been finalized that may affect these frequent questions. Additionally, these frequent questions have not been updated since Congress passed the Water Infrastructure Improvements for the Nation (WIIN) Act that paves the way for state coal ash permit programs. Please refer to the following rulemakings and the WIIN Act for more information:

- Extension of Compliance Deadlines and Response to Partial Vacatur <https://epa.gov/coalash/coal-ash-rule#extension>
- Amendments to the National Minimum Criteria Finalized in 2018 (Phase One, Part One) <https://epa.gov/coalash/coal-ash-rule#partonephaseone>
- State CCR permit programs and the WIIN Act <https://epa.gov/coalash/coal-ash-rule#permits>

In 2015, EPA finalized national regulations <https://epa.gov/coalash/coal-ash-rule> to provide a comprehensive set of requirements for the safe disposal of CCRs, commonly known as coal ash, from coal-fired power plants. Below are frequent questions about the 2015 rule:

1. What is coal ash?
2. How much coal ash is generated and disposed of each year?
3. How and where is coal ash currently generated and disposed?

3. **How and where is coal ash currently generated and disposed?**

   CCRs may be generated wet or dry, and some CCRs are dewatered while others are mixed with water to facilitate transport (e.g., sluiced).

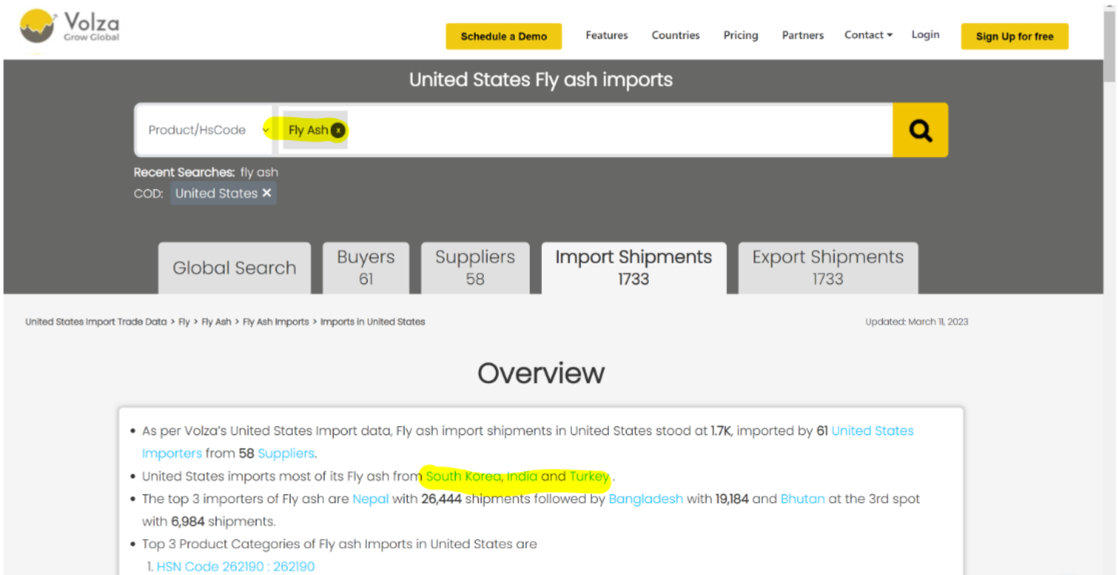
   CCRs can be disposed in off-site landfills, or disposed in on-site landfills or surface impoundments. In 2012, approximately 40 percent of the CCRs generated were beneficially used, with the remaining 60 percent disposed in surface impoundments and landfills. Of that 60 percent, approximately 80 percent was disposed in on-site disposal units. CCR disposal currently occurs at more than 310 active on-site landfills, averaging more than 120 acres in size with an average depth of over 40 feet, and at more than 735 active on-site surface impoundments, averaging more than 50 acres in size with an average depth of 20 feet.

4. **Why is EPA regulating coal ash?**

   EPA determined that improperly constructed or managed coal ash disposal units have been linked to cases of harm to surface or ground water or to the air. This new rule addresses the risks from coal ash disposal identified in these cases -- leaking of contaminants into groundwater, blowing of contaminants into the air as dust, and the catastrophic failure of coal ash surface impoundments such as what occurred at TVA's Kingston, Tennessee facility -- by adding new requirements for coal ash surface impoundments and landfills.

5. **What is EPA's Coal Ash Surface Impoundment Integrity Assessment Program?**

   The Coal Ash Surface Impoundment Integrity Assessment Program was a comprehensive evaluation undertaken by EPA to evaluate the condition and safety of coal ash ponds nationwide. By March 2009, EPA had begun field work to assess all above-grade coal ash surface impoundments – more than 500 units located at over 200 power plants – and by 2012 had concluded one of the largest targeted field assessments ever conducted by EPA. In response to the assessments, power plants took actions to help ensure structural stability, thus greatly enhancing environmental and public health protection. In addition, to promote transparency, the information generated through these engineering assessments has been posted on EPA's web site and made available to the public.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Updated: March 11, 2023
Overview
As per Volza's United States Import data, Fly ash import shipments in United States stood at 1.7K, imported by 61 United States Importers from 58 Suppliers.
United States imports most of its Fly ash from South Korea, India and Turkey.
The top 3 importers of Fly ash are Nepal with 26,444 shipments followed by Bangladesh with 19,184 and Bhutan at the 3rd spot with 6,984 shipments.
Top 3 Product Categories of Fly ash Imports in United States are
1. HSN Code 262190 : 262190