Maryland State Highway Administration

Concrete Plant Technician Certification

Concrete 101

By

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Concrete Design

Concrete is designed for:

1. Strength
2. Place-ability
3. Durability

Strength

The required strength of concrete is determined by engineers based on the loads and stresses that will be placed on the structure. Strength is very strongly related to the total amount of cementitious content in the concrete and the water to cementitious ratio (WCR). *For Maryland State Highway Administration structures, compressive strength, maximum WCR, and minimum cementitious contents can be found in Table 902A for each mix*.

Place-ability

Place-ability refers to the ability of concrete to be placed by a given method into the final form. Examples would be pumping concrete into a stem wall full of heavily congested re-bar. In this case, the concrete would need to flow readily to make it through the pump and the reinforcing steel. Another example would be a curb and gutter that was going to be placed with a slip form paver. In this example, you would need a concrete that was very tight (low slump) and did not readily flow. Place-ability is measured by slump and requirements can be found in Table 902A.

Durability

Durability of concrete is the ability of a structure to withstand chemical and physical attack. The typical types of attack on concrete structures are:

1. Sulfate attack – sulfates are found in sea water and brackish water and can cause a mineral called ettringite to form in concrete. Ettringite expands in the concrete and causes it to crack. The Maryland State Highway Administration requires that Type II cement be used in sulfate environments. Type I cement may be used if testing (ASTM C1012) is performed with fly ash or slag cement and moderate sulfate resistance is demonstrated.

2. Alkali Silica Reaction (ASR) – alkali silica reaction occurs when alkalis (from portland cement) react with silica found in some coarse or fine aggregate. The reaction forms an expansive gel which causes the concrete to crack. The Maryland State Highway Administration requires that slag cement or flyash as prescribed be used with reactive aggregates and prohibits the use of highly reactive aggregates.

3. Resistance to freeze thaw damage – freeze thaw damage occurs when water in concrete freezes and there is a poor air void system (for exterior concrete, air is intentionally entrained into the concrete) or when the concrete is too weak to withstand the forces of the freezing water. The Maryland State Highway Administration places limits on the amount of air in the concrete (Table 902A), the minimum amount of cementitious material in the concrete (Table 902A), the maximum amount of fly ash (25%) and slag cement (50%) in the concrete, and the maximum water to cementitious material (WCR) of the concrete (Table 902A).

4. Resistance to chloride intrusion – chlorides cause reinforcing steel to corrode and results in concrete cracking around the corroding steel. Fly ash, slag cement, and silica fume are all good materials for reducing the permeability of the concrete, which reduces the amount of chlorides that can get down to the reinforcing steel. The amount of cement in a concrete mix also influences the permeability of the concrete, with higher cement factors having lower permeability. Minimum limits for the amount of cementitious materials are in Table 902A.

5. Set related issues – Set time issues occur when concrete sets to quickly or to slowly. Set issues can lead to cracking, excessive water demand, and low concrete strengths. Set is related to the types and amounts of materials in the concrete mixes, but it is also very strongly associated with the ambient temperature and the temperature of the concrete. Table 902A places limits on each concrete mixture.

Concrete Mix Design Basics

Density of water
The density of water is 62.4 lb/ft^3

Conversion factor for water
One gallon of water weighs 8.33 lbs.

Specific gravity (SpGr)
Specific gravity is the ratio of the density of a material over the density of water. Specific gravity is used to convert weight to volume or volume to weight.

Example:
Convert weight (lbs) to volume (ft^3)

If your sand in the mix weighs 1400 lbs and it has a specific gravity of 2.57, the volume of the sand would be:

$$\frac{Weight\ of\ Material}{SpGr\ of\ Material\ x\ Density\ of\ Water} = \frac{1400}{2.57\ x\ 62.4} = 8.73\ ft^3\ of\ sand$$

Volume of Concrete
Concrete is sold by the cubic yard. Each cubic yard of concrete contains 27 cubic feet of concrete.

Apparent vs. Absolute Volume (Aggregate and Cementitious)
When aggregate or cementitious material is packed together, there are spaces between the particles. These spaces make the volume larger, the more and larger the spaces, the larger the volume. The volume with these materials with the voids is called the apparent volume. The volume of these materials without the voids is called the absolute volume. Concrete is designed with absolute volume of materials.

Water to Cementitious Ratio (Cementitious includes cement, slag cement, and fly ash)
One of the most important factors in designing a concrete mixture is the water to cementitious ratio (WCR). The water cementitious ratio is the weight of water in the concrete (1 gallon of water = 8.33 lbs.) divided by the weight of the cementitious material in the mix (cement + slag cement + fly ash). In general, the lower the amount of water in a mix, the lower the WCR, the higher the strength of the mix.

More water / Higher WCR = lower strength and decreased durability

Designing Mixes
Concrete mixes are designed using engineering concepts and engineering judgement based on over a century of concrete experience. Engineers and technologists follow codes, specifications, strength requirements, durability requirements, and placement considerations to determine the amount of each material that will be included in a concrete mix.

Prescriptive Specs
Maryland State Highway Administration specifications are prescriptive, meaning the state prescribes limits for many of the constituent materials in the mixes as well as the plastic and hardened properties. The limits can be found in Table 902A. This table is extremely important to study because you can find, for any given mix, the required:

1. Strength
2. Minimum cement content
3. Coarse aggregate size
4. Maximum water to cementitious ratio
5. Slump range
6. Air content range
7. Concrete temperature range

The following is a copy of the table. The full table with notes can be found in the 902 section of the MSHA specifications.

Table 902A

PORTLAND CEMENT CONCRETE MIXTURES										
MIX NO.	SPECIFIED ACCEPTANCE COMPRESSIVE STRENGTH psi	COMPRESSIVE STRENGTH ACCEPTANCE TEST AGE days	STD. DEV. psi	CRITICAL VALUE psi	MIN CEMENT FACTOR lb/yd³	COARSE AGGREGATE SIZE M 43 / M 195	MAX WATER/ CEMENT RATIO by wt	SLUMP RANGE in.	TOTAL AIR CONTENT %	CONCRETE TEMP. °F
1	2500	28	375	2430	455	57, 67	0.55	2 - 5	5 - 8	50 - 95
2	3000	28	450	3010	530	57, 67	0.50	2 - 5	5 - 8	50 - 95
3	3500	28	525	3600	580	57, 67	0.50	2 - 5	5 - 8	50 - 95
4	3500	28	525	3600	615	57, 67	0.55	4 - 8	N/A	50 - 95
5	3500	28	525	3600	580	7	0.50	2 - 5	5 - 8	50 - 95
6	4500	28	675	4770	615	57, 67	0.45	2 - 5	5 - 8	50 - 80
7	4200	28	630	4420	580	57	0.50	1½ - 3	5 - 8	50 - 95
8	4000	28	600	4180	750	7	0.42	2 - 5	5 - 8	50 - 80
9	3000	(a)	N/A	N/A	800	57, 67	0.45	4 - 8	5 - 8	60 - 100
10	4500	28	675	4770	700	¾" – No. 4	0.45	2 - 5	6 - 9	50 - 80
11	4200	28	630	4420	—	57, 67	0.45	2 - 5	5 - 8	50 - 80
12	4200	28	630	4420	—	¾" – No. 4	0.45	2 - 5	6 - 9	50 - 80
HE	3000	(b)	N/A	N/A	N/A	N/A	N/A	3 - 9	5 - 8	60 - 100
PC (c)	N/A	N/A	N/A	N/A	450	7, 8	0.45	N/A	15 - 25	N/A
WT	2500	(d)	NA	NA	650	57	0.45	5 max	5 - 8	50 - 95

Proportioning (Submittal of Mix Design and Material Sources)

Prior to the start of construction, you need to submit to the AME the source and proportions of materials to be used for each concrete mix. The mixture needs to meet 902.10.03 of the MSHA specification. The concrete, with the exception of water and chemical admixtures, are proportioned by weight. Water and chemical admixtures may be proportioned by volume or weight. The mix needs to be uniform and workable.

Trial Batches

Trial batches are used to verify that a new mix will achieve the specified criteria for a mix (strength, air content, slump, etc.). The AME should be notified 2 weeks in advance of a trial batch. Trial batches shall be composed of at least 3 cubic yards of concrete. The AMA may wave trial batches if performance records show the mix will meet the average strength requirements.

Triggers for a Verification Trial Batch

Changes in cement type, slag cement grade, coarse or fine aggregate, admixture brand, or mixture proportions can trigger a trial batch to verify that the concrete mix still meets State requirements.

Concrete Mix Example

Given: 620 lbs. total cementitious, 25% slag cement

	SpGr	Absorption
Portland Cement	3.15	
Slag Cement	2.93	
Coarse Aggregate	2.79	0.2
Fine Aggregate	2.68	0.7

Material	Weight / Amount	Volume
Cement	465 lbs.	$= \frac{Weight\ of\ Cement}{SpGr\ of\ Cement\ x\ Density\ of\ Water} = \frac{465}{3.15\ x\ 62.4} = 2.37\ ft^3$
Slag Cement	155 lbs.	$= \frac{Weight\ of\ Slag\ Cement}{SpGr\ of\ Slag\ Cement\ x\ Density\ of\ Water} = \frac{155}{2.93\ x\ 62.4} = 0.85\ ft^3$
Coarse Aggregate	1800 lbs.	$= \frac{Weight\ of\ Coarse\ Aggregate}{SpGr\ of\ Coarse\ Agg\ x\ Density\ of\ Water} = \frac{1800}{2.79\ x\ 62.4} = 10.34\ ft^3$
Fine Aggregate	1240 lbs.	$= \frac{Weight\ of\ Fine\ Aggregate}{SpGr\ of\ Fine\ Agg\ x\ Density\ of\ Water} = \frac{1240}{2.68\ x\ 62.4} = 7.41\ ft^3$
Water	33 gal	$= \frac{Weight\ of\ Water}{Density\ of\ Water} = \frac{33\ x\ 8.33}{62.4} = \frac{275}{62.4} = 4.41\ ft^3$
Air (%)	6%	= 0.06 x 27 = $1.62\ ft^3$
Total Volume		$27\ ft^3$
Water Reducer	3 oz./cwt	
Air Entrainer	0.4 oz./cwt	

Coarse Aggregate Moisture
Weight of Pan = 112.3 g
Weight of Pan + Wet aggregate = 4310.4 g
Weight of Wet Aggregate = 4310.4 g – 112.3 g = 4198.1 g
Weight of Dry Aggregate = 4185.9 g

%Total Moisture = $\frac{Weight\ of\ Wet\ Aggregate - Weight\ of\ Dry\ Aggregate}{Weight\ of\ Dry\ Aggregate} = \frac{4198.1-4185.9}{4185.9}\ x\ 100 = 0.3\%$
% Free Moisture = % Total Moisture - % Absorption = 0.3 - 0.2 = 0.1%

Fine Aggregate Moisture
Weight of Pan = 65.4 g
Weight of Pan + Wet Aggregate = 575.3 g
Weight of Wet Aggregate = 575.3 – 65.4 = 509.9 g
Weight of Dry Aggregate = 485.3 g

% Total Moisture = $\frac{Weight\ of\ Wet\ Aggregate - Weight\ of\ Dry\ Aggregate}{Weight\ of\ Dry\ Aggregate} = \frac{509.9-485.3}{485.3}\ x\ 100 = 5.1\%$
% Free Moisture = % Total Moisture - % Absorption = 5.1 – 0.7 = 4.4%

Mix Corrected for Moisture

Material	Batch Weight per yd^3	Batch Weight per 10 yd^3
Cement	465 lbs.	= 465 x 10 = 4650 lbs.
Slag Cement	155 lbs.	= 155 x 10 = 1550 lbs.
Coarse Agg	= 1800 + 1800 x 0.001 = 1802 lbs.	= 1802 x 10 = 18020 lbs.
Fine Agg	= 1241 + 1241 x 0.044 = 1296 lbs.	= 1296 x 10 = 12960 lbs.
H_2O	= 33 x 8.33 – 1800 x .001 – 1241 x 0.044 = 218 lbs.	= 218 x 10 = 2180 lbs.
H_2O Reducer	= 3 x $\frac{620}{100} = 18.6\ oz.$	=18.6 x 10 = 186 oz.
Air Entrainer	= 0.4 x $\frac{620}{100} = 2.5\ oz.$	= 2.5 x 10 = 25 oz.

For this example, 2 lbs. of free water were contributed by the coarse aggregate and 55 lbs. by the fine aggregate. This water needs to be subtracted by the mix water. 33 gallons x 8.33 = 275 lbs. of water – 55 lbs. from sand and 2 lbs. from the stone = 218 lbs. So for a 10 cubic yard load, you need to adjust your mix water down by 570 lbs. or 68 gallons to account for the water being added by the aggregates.

If your moistures were off on your sand by 1% (3.4% instead of 4.4%), the difference in water would be 124 lbs. or 15 gallons. 15 gallons of water would result in about an inch and a half additional slump, 1.5% additional air, and 300 psi strength decrease. It is obvious then, that determining the correct moisture in the aggregate is critical for the consistency of the concrete mix.

Materials

Cementitious Material
There are two types of cementitious materials allowed by MSHA. Cement like materials, such as portland cement and slag cement only require the addition of water to gain strength. Pozzolanic materials, like fly ash and silica fume, require a source of lime (provided from the reaction with portland cement) and water to gain strength.

Cementitious materials for State work includes:

1. Portland cement
2. Slag cement
3. Class F fly ash
4. Class C fly ash
5. Silica fume
6. Blended cements (Portland + fly ash or slag cement)

Minimum Cement Factor (Content)
The minimum cement content is the total amount of cementitious material.

Minimum Cement Factor = portland + slag cement + fly ash + silica fume

Water Cement Ratio Calculation
The water cement ratio equals the weight of all the mixing water divided by the weight of all the cementitious materials in the mix.

$$\text{The Water Cement Ratio} = \frac{Weight\ of\ All\ Mixing\ Water\ (Added+Free+Ice+Admixture)}{Weight\ of\ Portland\ Cement\ +Slag\ Cement+Fly\ Ash+Silica\ Fume}$$

Portland Cement

Portland cement is produced by finely blending sources of silica, calcium, and iron and heating them in a huge rotating kiln at very high temperatures. The material that comes out of the kiln is called clinker. This material is ground again in a ball mill and some form of gypsum is added to control the early set of the concrete.

Typical raw materials used for the sources of lime, silica, alumina and iron are:

1. Lime – Limestone
2. Silica – Clay, fly ash, sand
3. Alumina – Bauxite, clay, shale
4. Iron – Iron ore, mill scale

There are three major types of cement:

1. *Type I – general purpose*
2. *Type II – moderate sulfate resistance*
3. *Type III – High early strength*

The major compounds in cement are:

1. Tricalcium aluminate (C3A) – responsible for early strength and set characteristics
2. Tricalcium silicate (C3S) – responsible for early and 28 day strength
3. Dicalcium silicate (C2S) – responsible for strength beyond 28 days
4. Tetracalcium Aluminoferrite (C4AF) – responsible for color in the concrete

***Blaine (Fineness)**
Cement is ground to a specified fineness referred to as Blaine. The higher the Blaine, the finer the cement. Finer cements with higher Blaines will produce higher early strengths. Generally, they will also increase shrinkage of the concrete.

***Cement Hydration**
When cement is mixed with water, it starts a complex chemical reaction called cement hydration. The C3A, C3S, C2S, and C4AF combine with the water and form calcium silicate hydrate and calcium hydroxide. Calcium silicate hydrate (CSH) is the glue that provides strength to the concrete. Calcium hydroxide (CaOH) is a by-product that by itself creates no strength in the concrete but it can be used by slag cement, fly ash, or silica fume to form additional calcium silicate hydrate.

Cement + Water = Calcium Silicate Hydrate (CSH) + Calcium Hydroxide (CaOH)

***Requirements for Portland Cement**
1. *Meets AASHTO M85*
2. *Maximum allowable temperature is 170^{o}F*

Sampling Portland Cement
1. *10 lb. sample in a plastic screw cap (approximately 4" diameter) jar*
2. *One sample every two weeks when producing State work*
3. *One sample every month when little or no State concrete is being produced*

Fly Ash

Fly ash is a by-product of the manufacture of energy in a coal fired power plant. When coal is burned, fine material is collected before it exits the smoke stacks. This material that is collected is called fly ash and it contains silica, alumina, and calcium oxides.

There are two basic types of fly ash, Class F fly ash and class C fly ash. Class F fly ash has a much lower amount of calcium oxides that Class C. Most fly ashes on the east coast are Class F.

Class F fly ash is a pozzolan and reacts very well with the calcium in portland cement mixtures. In general, Class F fly ash mixes have about 95% of the strength of a straight portland cement mix. Class F fly ash provides the concrete with decreased permeability, increased resistance to ASR and sulfate attack, and is easier to finish then straight portland cement mixes. Fly ash slows the set of concrete.

AASHTO Requirement for Fly Ash

Must meet the requirements of AASHTO M295, pozzolan, Class C or F.

Loss on Ignition (LOI)

Loss on ignition is a measure of the amount of carbon from the coal that is still left in the fly ash. The higher the LOI, the more carbon. Carbon can dramatically affect air in concrete so a fly ash with a high or variable LOI may be a concern. Most fly ashes today are beneficiated (have the carbon removed) and have little effect on air. The state limits LOI in fly ash to 3.0 percent.

Substitution Limit

Fly ash can be substituted up to a maximum of 25% of the weight of cement.

Sampling of Fly Ash

1. *10 lb. sample in a plastic screw cap (approximately 4" diameter) jar*
2. *One sample every two weeks when producing State work*
3. *One sample every month when little or no State concrete is being produced*

Slag Cement

Slag cement is a by-product of the manufacture of iron in a blast furnace. Iron ore and limestone are heated in a blast furnace to very high temperatures until they become liquid. The furnace is tapped and the molten material flows down a channel. Iron is dense and it sinks to the bottom while all the impurities (the slag) float on the top. A gate separates the iron from the slag and the slag flows down to a runner where it is quenched with water (granulation). The granulated slag is then ground to a fineness a little greater than that of portland cement. Slag cement is high in calcium and silica.

Slag cement increases the ultimate strength of the concrete, reduces permeability, and increases the resistance to ASR and sulfate attack. Slag cement concrete is easier to finish than straight portland cement concrete. Slag cement concrete slows the set of concrete.

AASHTO Requirement for Slag Cement
Must meet the requirements of AASHTO M302, Grade 100 or Grade 120.

Substitution Limit
Slag cement can be substituted up to a maximum of 50% by weight.

Sampling

1. *<u>10 lb. sample in a plastic screw cap (approximately 4” diameter) jar</u>*
2. *<u>One sample every two weeks when producing State work</u>*
3. *<u>One sample every month when little or no State concrete is being produced</u>*

Silica Fume

Silica fume is the by-product of the manufacture of silicon or ferro-silicon metals in an arc furnace. When these metals are made at very high temperatures, the dust collected in the smoke stack is called silica fume. It is extremely fine and largely composed of silicon oxides. Silica fume is very good at achieving very high strength and dramatically lowers the permeability of concrete. Silica fume also can help lower the risk of ASR and sulfate attack. Because of its fineness, silica fume makes concrete sticky and dramatically reduces or eliminates bleed water, which can lead to cracking problems in the field if the concrete is not cured properly.

ASTM Requirement for Silica Fume
Must meet the requirements of ASTM C1240 (the oversize requirement is waived).

Substitution Limit
Silica Fume can be substituted between 5% and 7% by weight.

Sampling

1. *<u>10 lb. sample in a plastic screw cap (approximately 4” diameter) jar</u>*
2. *<u>One sample every two weeks when producing State work</u>*
3. *<u>One sample every month when little or no State concrete is being produced</u>*

Blended Hydraulic Cement

Blended hydraulic cement is an intimate and uniform blend of portland cement with fly ash or slag cement.
AASHTO and MSHA Requirements for Blended Cement
Must meet the requirement of AASHTO M 240 Type IP containing 15 to 25 percent Fly Ash by weight of cement or Type 1S containing 25 to 50 percent slag cement by weight of cement.

Maximum loss on ignition is 3.0 percent. The requirement for a manufacturer's written statement of the chemical composition is waived.

ADMIXTURES

Admixtures are used largely to enhance the performance of the concrete, either by lowering the amount of water required to achieve a given slump (thereby increasing strength) or altering the set time of the concrete (faster in winter, slower in summer).

Basic Requirements

1. Dispensers are visible, easily read, and calibrated
2. Prevent admixtures from freezing
3. All dispensers need to be flushed regularly to clean them

Main Admixture Types

1. Type A – water reducing
2. Type B – set retarding
3. Type C – set accelerating (Only non-chloride allowed)
4. Type D – Water reducing and retarding
5. Type E – Water reducing and accelerating
6. Type F – High range water reducer
7. Type G – High range water reducer and retarder
8. Air entraining admixtures

Types Allowed for Structural Work
Types A or D

Types Allowed for Work Deemed Non-Structural
Type F and G - Use Type F for early strength, which needs to produce a minimum compressive strength in 12 hours of 180 percent of that of the control. Use Type G when early strength is not specified. The manufacturer needs to furnish certification as specified in TC-1.03. The certification needs to include curves indicating the fluid ounces of admixture per 100 lb of cement as related to water reduction and strength gain for 12 hours when used with a minimum cement factor of 700 lb.

AASHTO Requirement for Type A-G Admixtures
Must meet the requirement of AASHTO M 194, Type A, D, non-chloride C, F and G.

AASHTO Requirement for Air Entraining Admixtures
Must meet the requirements of AASHTO M154.

Type A and D admixtures allows you to place concrete with a lower wcr for the same slump.

Type D admixtures also provide retardation and will generally increase the strength to a small degree over Type A admixtures.

Non-chloride Type C admixtures are used to accelerate the set time of the concrete and do not contribute to the corrosion of reinforcing steel.

Air entraining admixtures should never be added to the concrete at the same time as other admixtures.

Factors that Affect Air Entrainment – Air is one of the most difficult factors to control in concrete. It is affected by concrete and ambient temperature, aggregate type and gradation, and age of the concrete, among several other factors. Some of the factors that affect air are:

Factor	Effect on Air
Increasing Temperature	Decreases air
Cement alkalis	Increase in alkalis increases air
Fineness	Increasing fineness decreases air
Fly Ash LOI	Increase in LOI will decrease air
Fine Aggregate (No. 30 and No. 50)	Increase in size factions will increase air
Fine Aggregate (No. 100)	Increase in size faction will decrease air
Admixtures	Some admixtures can dramatically increase air
Long Haul Distances	Decreases air
Retempering	Increases air
Pumping Concrete	Can decrease air if not done properly
Water / Slump	Increases with increasing slump up to about 6-8 inches, after which it decreases

Corrosion Inhibitors – Need to be calcium nitrite based and contain a minimum of 30 percent active ingredients by mass. The gallonage of corrosion inhibitor used in the concrete mixture needs to be included as water when determining the water/cementitious materials ratio.

Synthetic Fibers - When synthetic fibers are specified in the Contract Documents, the fibers need to be 1/2 to 1-1/2 in. long and conform to ASTM C 1116, Type III. The manufacturer needs to furnish certification as specified in TC-1.03. The quantity of fibers used and their point of introduction into the mix needs to conform to the fiber manufacturer's recommendations.

Macro Polyolefin Fibers – Need to meet ASTM D 7508 with a minimum length of 1-1/2 in.

Water

The amount of water in a concrete mix includes the water added at the plant, ice, water from admixtures, free water from aggregate, wash water, and water added at the job site.

The source of water shall be tested and approved by Maryland State Highway Administration, shall be clear and shall meet the requirements of AASHTO T26, Method B. Chlorides in water shall not exceed 500 ppm. Water meters shall be calibrated. The temperature of mixing water shall not exceed 170 ^{o}F.

Retempering – Retempering refers to the addition of water at the jobsite. Batch tickets indicate the maximum allowable water and the amount of water that can be added based on the specified wcr. A maximum of 3 gallons of water per cubic yard can be added. No water can be added after the partial discharge of the load.

Effect of Water Addition on Concrete Properties - The addition of water has a dramatic effect on concrete properties. A good rule of thumb is that adding a gallon of water (per cubic yard of concrete) will increase slump by 1 inch, will increase air by 1%, and will decrease strength by 200 psi.

Aggregate

Aggregate, both coarse and fine, have a tremendous effect on plastic and hardened properties of concrete. They comprise 60 to 70% of the concrete mix and they affect strength, workability, finishability, pumpability, and water demand. Most of the materials that are used in concrete are pre-certified. Aggregate should arrive at the concrete plant in spec but gradations can change with handling and properties need to be verified. Also, the moisture condition of aggregate is critical for manufacturing concrete within spec and it needs to be carefully monitored.

Particle shape, texture, and size distribution has a tremendous effect on concrete properties.

Particle shape – refers, as the description implies, to the relative shapes of the coarse aggregate particles. For coarse aggregate, cubical particles make much better concrete than flat and elongated particles. Flat and elongated particles have a higher surface area and require excessive amount of paste to cover them and increase the water demand of the concrete. They also make finishing more difficult and can cause concrete pumps to block up. **For these reasons, flat and elongated particles are limited to 15% by weight of the total aggregate.**

Particle texture (Coarse Aggregate) – refers to whether the coarse aggregate is rounded and smooth, like a gravel, or angular, lie a crushed stone. Smooth rounded particles have a lower water demand but also have less bond with the paste. Concrete made with this aggregate is generally easier to pump and finish. Angular particles have higher water demand but better bond to the paste. They also usually make concrete with higher strength.

Particle texture (Fine Aggregate) – for fine aggregate, texture usually refers to whether the sand is natural or manufactured. Manufactured sand is very angular compared to natural sand. Most manufactured sands are blended with natural sand because the mixes would be too harsh if used alone.

Particle size distribution – refers to the different size of particles of the aggregate, broken down by various sieves. Particle size distribution is extremely important for almost every hardened and plastic property of the concrete. AASHTO specifies bands for each aggregate size that aggregates are required to meet.

Particle Size and Surface Area – The smaller the aggregate size the higher the surface area of the aggregate and the more paste that is required to cover the aggregate – generally the higher the shrinkage of the concrete.

Gradation

Frequency – 2 Samples per 8 hour shift

Accuracy – Calculate percent passing to the nearest 0.1 percent.

Sieve Analysis Calculation / Coarse Aggregate:

Coarse Aggregate Gradation (#57 Stone)						
Sieve	Weight Retained	Weight Passing		% Passing		Specification
1 ½"	0	27.63 – 0 =	27.63	27.63/27.63 x 100 =	100	100
1"	0.64	27.63 - 0.64 =	26.99	26.99/27.63 x 100 =	97.7	95-100
½"	20.91	26.99 – 20.91 =	6.08	6.08/27.63 x 100 =	22.0	25-60
No. 4	5.7	6.08 – 5.7 =	0.38	0.38/27.63 x 100 =	1.4	0-10
No. 8	0.19	0.38 - .19 =	.19	0.19/27.63 x 100 =	0.7	0-5
Pan	0.19	* Note that gradation does not meet specification limits				
Total	27.63					

Sieve Analysis calculation / Fine Aggregate:

Fine Aggregate Gradation						
Sieve	Weight Retained (g)	Weight Passing (g)		Total % Passing Each Sieve		Specification % Passing
3/8	0	495	495	=495/495 x 100 = 100	100	100
No. 4	14.8	495 – 14.8 =	480.2	= 480.2/495 x 100 = 97.0	97.0	95 - 100
No. 8	44.0	480.2 – 44.0 =	436.2	= 436.2/495 x 100 = 88.1	88.1	
No. 16	153.9	436.2 – 153.9 =	282.3	= 282.3/495 x 100 = 57.0	57.0	45 – 85
No. 30	153.9	282.3 – 153.9 =	128.4	= 128.4/495 x 100 = 25.9	25.9	
No. 50	32.2	128.4 – 32.2 =	96.2	= 96.2/495 x 100 = 19.4	19.4	10 – 30
No. 100	83.3	96.2 – 83.3 =	12.9	= 12.9/495 x 100 = 2.6	2.6	0 - 10
Pan	12.9					
Total	495.0					

The following is the required gradation (AASHTO T27) for each aggregate allowed for use in State Work:

Sieve Size	Coarse Aggregate				Fine	
	#57	#67	#7	LWT	NWT	LWT
	Gradation - Mass Percent Passing					
1-1/2”	100					
1”	95-100	100		100		
¾”		90-100	100	90-100		
½”	25-60		90-100			
3/8”		20-55	40-70	10-50	100	100
No. 4	0-10	0-10	0-15	0-15	95-100	85-100
No. 8	0-5	0-5	0-5			
No. 16					45-85	40-80
No. 50					5-30	10-35
No. 100					0-10	5-25

Definition of Confusing Terms

Maximum size – Smallest size through which the entire sample is required to pass.

Maximum nominal size – Smallest size through which the entire sample is permitted to pass.

So for a #57, the maximum size is 1 ½” and the nominal maximum size is 1”, for a #67, the maximum size is 1” and the nominal maximum size is ¾”, and for a #7, the maximum size is ¾” and the maximum nominal size is ½.”

Fineness Modulus (fm) for Sand – Fineness modulus is an indirect measure of the fineness of the sand. Smaller fm’s indicate a finer sand and larger fm’s indicate a coarser sand. Fineness modulus is important because it can indicate a change in product that can affect concrete properties. For instance, if the fineness modulus decreases (sand becomes finer), there might be an increase in water demand and the concrete may be easier to finish (until it gets too fine and is sticky). High fm’s (coarser sands) may be less easy to finish but will make concrete with higher strength.

The following table shows you how to calculate the fineness modulus:

Fineness Modulus (FM) Calculation	
Sieve	% Passing
3/8	100
No. 4	97.0
No. 8	88.1
No. 16	57.0
No. 30	25.9
No. 50	19.4
No. 100	2.6
Total	390.0
FM	= (700 – 390)/100 = 3.10 (700 is a constant)
Specification	= Between 2.3 and 3.1 and +/- 0.20 of the base FM

Base fm – Average fm for last 10 tests or average for all samples if there are less than 10 samples.

Sampling Aggregate: In order to obtain an accurate gradation, you need to get a proper sample. <u>Samples should be gathered at the last practical point where they can be gathered.</u> This means that you need to grab your samples as close as you safely can prior to their introduction to the mixer (in the ready mix truck or in the central mixer).

Sample sizes *(Samples should be gathered in accordance with AASHTO T2)***:**

Material	**Sampling (Min.) AASHTO T2**	**Sieve Analysis (Min.) AASHTO T27**	**Moisture (Min.) (MSMT 251)**
Sand	**22 lbs.**	**300 g**	**500 g**
#57	**110 lbs.**	**22 lbs. / 10,000 g**	**1000 g**
#67	**55 lbs.**	**11 lbs. / 5000 g**	**1000 g**
#7	**35 lbs.**	**4 lbs. / 2000 g**	**500 g**

Reducing Samples – Mix and reduce samples in accordance with AASHTO T 248

Examples:

Grabbing Samples from the flowing aggregate stream

1. Obtain 3 samples at equal intervals
2. Grab sample from entire discharge
3. Make sure pan is of sufficient size to intercept entire discharge without overflowing

Grabbing samples from conveyor belt

1. Obtain 3 samples at equal intervals
2. Stop conveyor belt before grabbing samples
3. Insert two templates whose shape conforms to that of the belt
4. Scoop out material between templates

Reducing Samples to size required for test

Splitters – When splitting samples for testing, use a splitter with an even number of chutes, 8 chutes for coarse aggregate, 12 chutes for fine aggregate. The minimum width of the chute should be 50% larger than the largest particle. The maximum width for fine aggregate is ¼ inch.

Quartering

Miniature Stockpile Sampling -

Impurities

Aggregates are dug out of the ground, are not completely uniform, and may contain substances that are harmful to concrete. The following table shows the test methods and the limits for these materials:

	Sodium Sulfate Soundness	Clay Lumps or Friable Particles	Chert Less than 2.40 SpGr	Sum of Clay Lumps, Friable Particles and Chert	Materials Finer than 200 Sieve	Coal and Lignite	Flat and Elongated	L.A. abrasion	Organic Impurities
Test Method	T104	T112	T113	T112 & T113	T11	T113	D4791 (a)	T96	T21
Coarse Aggregate	12	2.0	3.0	3.0	1.0	0.5	12	50	-
Fine Aggregate	10	3.0	-	-	4.0	0	-	-	3.0

Sodium Sulfate Soundness – Shows resistance to weathering in freeze thaw environment.

Clay Lumps or Friable Particles – Can cause pitting on surface of the concrete and water demand issues.

Chert – Highly absorptive particles that can cause pop outs on the surface of the concrete.

Material Finer that 200 Sieve – Can cause water demand and poor aggregate bond.

Coal and Lignite – Can cause discoloration on the surface of the concrete.

Flat and Elongated – Can cause excessive water demand, finishing issues, and pumping issues.

Los Angles Abrasion – Measure resistance to abrasion and wear.

Organic Impurities – May interfere with the cement hydration process.

Dust of Fracture – Dust of fracture refers to the fine dust that results from crushing the rock. A small amount is beneficial to the concrete but excessive amounts can increase water demand, affect bond strength with paste, and result in lower concrete strengths.

Wash Test – A wash test is a method of using water to wash material in the sieves to collect very fine material that may cause problems, like clay or dust of fracture. When it is expected that this might be a problem, a wash test should be performed.

Moisture Content

Aggregates are similar to sponges. They are porous and have nooks and crannies that can fill with water. The amount of water in aggregate is important because it may figure in the mix water and affect the water cementitious ratio.

Aggregate Moisture Conditions:

Saturated Surface Dry (SSD) – Condition where all the nooks and crannies in the aggregate are filled with water but the surface of the aggregate is dry. For this condition, none of the water in the aggregate counts toward concrete mixing water.

Below SSD – Condition where the nooks and crannies in the aggregate are only partly filled with water. None of this water in the aggregate is counted toward the mixing water.

Above SSD – Condition where all the nooks and crannies are filled with water and there is excess water on the surface of the concrete. The excess water is called free water and needs to be counted as part of the mixing water.

Dry – There is no water in the aggregate.

Moisture Terminology:

Absorption – The percentage of water in the aggregate when the concrete is at SSD.

Free Water – The percentage of water in the aggregate in excess of SSD. This water needs to be counted as part of the mixing water.

State Requirement for Aggregate Moisture – For State work, all aggregate will be maintained in excess of SSD and free water will need to be calculated and added as part of the mixing water.

Moisture Determination

1. Minimum sample size
   a. 1000 g for #57 stone
   b. 1000 g for #67 stone
   c. 500 g for #7 Stone
   d. 500 g for sand

2. Weigh pan (Record to the nearest 0.1g)

3. Weigh pan and aggregate

4. Heat aggregate until all moisture is driven off (sample is dry when additional heating will not cause a 0.1 percent or greater additional loss in mass).

5. Use the following procedure to calculate the free moisture (water) in the aggregate and report to the nearest 0.1%:

$$\text{Total Moisture} = \frac{\textbf{Wet Weight} - \textbf{Dry Weight}}{\textbf{Dry Weight}} \text{ x } 100$$

Free Moisture = Total Moisture – Absorption

Remember to subtract the absorption in the end to calculate the free moisture and that the free moisture needs to be included into the calculation for the mixing water and the wcr.

Example:

Moisture Content Measurement and Calculation	
Sieve	% Retained
Pan Weight	55
Pan and Wet Agg. Weight	572
Wet Weight	= 572 – 55 = 517
Pan and Dry Agg. Weight	550
Dry Weight	= 550 – 55 = 495
% Moisture (Total)	= (517 – 495)/495 x 100 = 4.4
Absorption	0.8
Moisture Content (Free)	= 4.4 – 0.8 = 3.6

Moisture Probes: Most concrete plants use moisture probes to determine the amount of water in fine aggregate. Physical moisture tests of the aggregate needs to be **performed weekly** to make sure the probes are still reading correctly. They should also be performed to verify moisture after significant rain storms because moisture probes don't always pick up major moisture differences quickly.

State Specification for Moisture Probes:

915.03.02 Moisture Probes. Moisture probe readings may be used in place of actual daily moisture testing of fine aggregate. Moisture probes shall be calibrated and maintained per the manufacturer's recommendations.

(a) Actual moisture tests for fine aggregate shall be performed weekly and as directed. When the actual tests of the fine aggregate indicate a difference of greater than 0.5 percent free moisture than the moisture probe readings, immediately perform a second actual test.

(b) If the second test indicates a moisture difference of greater than 0.5 percent, recalibrate the moisture probe and verify. Records of all calibrations and weekly tests shall be maintained and made available.

Testing Concrete

Sampling – Grab a representative sample of concrete consisting of 2 or more samplings from the middle portion of the load of concrete (after the first third has been discharged and before the last third is being discharged). Grab the sample completely through the discharge stream of the concrete. Remix all samples with a scoop or flat shovel before testing.

Temperature – Temperature has an important effect on so many properties of the concrete that it should always be recorded when other concrete tests are being performed.

Place a calibrated thermometer in the concrete, provide 3 inches of cover in all directions around the probe, wait until the temperature readings stabilize and record to the nearest degree F.

> **915.03.03 Mixing Temperatures.** The plant shall be equipped with approved methods of heating and cooling the mix. The temperature of the plastic concrete shall meet 902.10.03. The temperature of the cementitious materials and water during mixing shall not exceed 170 F.

Strength – Standard cured strength specimens (cylinders) are manufactured to check the adequacy of the mix proportions for the specified strength. They do not represent the strength of the structure but they do give a strong indication that the mix was batched properly and that the materials are performing as they did in the trial batch.

Slump – Slump is a measure of the consistency of the concrete.

Fill a slump cone in three equal layers by volume. Rod each layer 25 times. Pull up the slump cone in 5 +/- 2 seconds. Measure down to the displaced original center of the concrete. Record to the nearest ¼ inch.

> Slump needs to meet the requirements in Table 902 A

Unit Weight – Unit weight gives a good indication that the materials were batched out properly, that the mix is not over or under yielding, and what the percentage of air is in the mix.

Weigh the empty container with a predetermined volume. Place concrete in the container in three equal layers, rodding each layer 25 times and consolidating each time by rapping the side of the container with a rubber mallet. On the final layer, provide about ¼ inch of excess concrete over the top of the container. Use a strike off plate to bring the concrete absolutely plane and level with the top of the container. Clean the container of excess concrete. Weigh the full container. Calculate the unit weight.

Example: Container volume = .25 ft^3. Weight of the empty container equals 8 lbs. Weight of the full container equals 45 lbs.

Weight of the concrete = Weight of the container filled with concrete – weight of the container
Weight of the concrete = 45-8 = 37 lbs.

$$Unit\ Weight\ of\ the\ concrete = \frac{Weight\ of\ the\ concrete}{Volume\ of\ the\ concrete} = \frac{37}{0.25} = 148.0\ lbs./ft^3$$

Air – Air effects strength, durability, and plastic properties of the concrete.

There are two ways to measure air, with a pressure meter or with a volumetric (roller) meter. Pressure meters are used for normal weight concrete and for plastic concrete (slump over an inch). Volumetric meters are used for light weight concrete. Pressure meters are calibrated to provide a set pressure on a carefully prepared (similar process to unit weight) pot of concrete. The pressure compresses air bubbles in the concrete and the meter indicates the total amount of air in the concrete. Volumetric meters use a much smaller pot and use water and alcohol to dissipate air bubbles. The total air is read in graduations on the neck of the Volumetric meter.

Air needs to meet the requirements of Table 902A.

Frequency of Tests - For field testing concrete on the jobsite, the following frequency is used:

TEST	METHOD	MINIMUM TEST FREQUENCY	RESPONSIBILITY
Temperature (e)	T 309	1 per 50 yd^3 (or fraction thereof)	Project Engineer
Slump (a)(e)	T 119	1 per 50 yd^3 (or fraction thereof)	Project Engineer
Air Content (a)(e)	T 152 T 196	1 per 50 yd^3 (or fraction thereof)	Project Engineer
Compression (b)(c)(d)	T 23	1 per 50 yd^3 (or fraction thereof)	Project Engineer
Compression (b)(c)(d) Mix No. 7 Only	T 23	3 per Day	Project Engineer

(a) A second test will be made when the first slump or air content test fails. Acceptance or rejection will be based on the results of the second test.
(b) Compressive strength tests are defined as the average of two companion cylinders.
(c) The Contractor shall be responsible for the making of all early break cylinders and furnishing the molds, stripping, curing/delivery of all cylinders, including 28 day cylinders, to the testing laboratory.
(d) The Project Engineer will be responsible for making, numbering and signing the 28 day cylinders.
(e) When constructing plain and reinforced concrete pavements, the testing frequency for slump, air content, and temperature shall be 1 per 100 yd3 or fraction thereof.

Plants

The Certified Plant Technician (CPT) is responsible to ensure that concrete plants and concrete trucks meet specification limits, that all materials meet specification limits, that all materials are collected and tested in accordance with State specifications, that there is testing equipment on site and that it is in working order, and that all paper work is properly filled out. The following is a list of some of the duties of the CPT to ensure that plant and truck requirements are met.

Certified Plant Technician Duties

1. Supervise all plant production
2. Ensure that the Quality Control Plan is followed
3. Sample materials according to the Sample Frequency Guide
4. Perform aggregate gradations
5. Perform moisture tests
6. Adjust proportions for free moisture
7. Sign batch tickets
8. Notify the State one working day prior to producing concrete for State projects.
9. Notify the State at least five working days in advance of scheduling the comprehensive inspection.

Quality Control Plan

Each plant is required to have a quality control plan. The following are the requirements for the Quality Control Plan:

1. A current Quality Control Plan exists and is approved
2. All QC Personnel are listed with an approved number
3. QC Plan is accessible to QA Inspectors and plant personnel
4. Changes to the Quality Control Plan are reported to SHA
5. Plant Quality Control Procedures are established and followed
6. Quality requirements of raw materials are specified

7. Sampling and Testing requirements are described

Laboratory

1. The quality control laboratory needs to be on site
2. The lab needs to have sufficient space to perform tests correctly and efficiently
3. The testing equipment needs to be in good working condition
4. The test records need to be maintained and available for review
5. An on-site office for State inspectors needs to be provided

Approved Material Sources

1. All materials used in producing concrete need to come from a SHA approved source
2. The production plant needs to keep on file all material sources and certification documents
3. Records need to be made available to the QA Inspector for review

Material Storage / Aggregate Stockpiles and Bins

1. Stockpiles and bins shall be kept separate for each type of aggregate
2. Stockpiles and bins should be accessible to loaders and to trucks bringing aggregate from the supplier
3. Aggregates need to be maintained at above SSD conditions
4. Aggregates need to be maintained to ensure uniform moisture conditions throughout the pile
5. There needs to be different compartments for each aggregate
6. Aggregates need to be stored in such a way as to prevent intermingling of different aggregates
7. Aggregate need to be stored and maintained in such a way as to prevent segregation

8. In cold weather, aggregates need to be protected from freezing (no frozen lumps) and aggregate should not be subjected to live steam

9. Aggregate bins should freely discharge

Material Storage / Cementitious

1. Silos should be in good condition

2. Silos should have no significant corrosion (Corrosion that would allow moisture into the silo or would cause contamination of materials between split silos)

3. Silos should be clearly marked (Cement / Fly Ash / Slag Cement)

Material Storage / Admixtures

1. Admixtures need to be properly stored as per manufacturer label

2. Batching accuracy for admixtures: Volumetric measurement need to be within 3% of the total amount required or plus or minus the volume of dose required for one sack of cement, whichever is greater (One sack of cement weighs 94 lbs.)

3. Most liquid admixtures will dose in ounces per 100 lbs. of cement (oz./cwt).

Batching Control

1. Scales should be zeroed out once at the beginning of the day's work.

2. Scales should stay zeroed but batch operator should check this before batching each load

3. Gates should be closed before batching (do not dump materials if charge gate is open)

4. Do not dump if material weights / doses are not within tolerance

Measuring Devices

1. All measuring devices, meters and dispensers need to be calibrated and certified annually by an approved testing agency

2. All measuring devices, meters and dispensers need to be calibrated and certified monthly by the producer or approved testing agency

3. For new plants, all measuring devices meters and dispensers need to be calibrated and certified by an approved agency

4. Balance and zero conditions need be checked daily and when requested by SHA personnel

5. Devices need to be checked monthly during operations

6. Notify the State 2 days prior to checks on calibration

Scale Certification

1. Scales need to be calibrated and certified annually by an approved testing agency

2. Scales need to be calibrated and certified monthly by the producer

3. Report should include:
    a. Calibration
    b. Maximum capacity
    c. Overall scale condition
    d. Include minimum graduation size

4. The concrete producer needs to notify the State 2 days prior to scale checks

Freefall

As aggregate falls in the weigh hopper, the weigh hopper can obviously only weigh the aggregate that is in the hopper. The aggregate in the air is the freefall aggregate, it hasn't hit the weigh hopper so it obviously hasn't been weighed yet. Estimating too much freefall (more aggregate in the air than there really is) will mean that you under weigh the aggregate. Estimating too little freefall (less aggregate in the air than there really is) will mean that you over weigh the aggregate.

Tolerances for Aggregate (AASHTO M157)

Operating Tolerances

1. Aggregate – 2.0% by weight

2. Cement – 1.0% by weight

3. Water – 1 gallon

4. Additives – 0.5% by volume

Measuring Cementitious with Tolerances

1. Cement is measured first

2. Slag cement or fly ash can be measured cumulatively but after portland cement is weighed first

Example: Mix calls for 5800 lbs. of portland cement and 1000 lbs. of fly ash.

1% tolerance for portland cement = 0.01 x 5800 = 58 lbs so tolerance is +/- 58 lbs. (5742 lbs. – 5858 lbs.)

1% tolerance for total cementitious = 0.01 x 6800 = 68 lbs. so tolerance is +/- 68 lbs. (6732 lbs. – 6868 lbs.)

Measuring Aggregate with Tolerances

1. Batch weights based on dry weight plus total moisture content

   Example: Batch weight for stone (with all water included from aggregate moisture) is 18,180 lbs.

   2% tolerance for stone = 0.02 x 18180 = 364 lbs. so tolerance is +/- 364 lbs. (17,816 lbs. - 18,544)

   Batch weight for sand (with all the water from aggregate moisture added) = 12,600 lbs.

   2% tolerance for sand = 0.02 x 12,600 = 252 lbs. so tolerance is +/- 252lbs. (12,348 – 12852)

   Batch weight for stone and sand (with all the water from aggregate moisture added is 30,780 lbs.

   2% tolerance for aggregate = 0.02 x 30,780 = 616 lbs. so tolerance is +/- 616 lbs. (30,164 lbs. - 31,396 lbs.)

Batch Tickets

Provide an approved computer generated batch ticket indicating the pertinent information for each load in duplicate. The ticket shall indicate maximum allowable water and maximum water allowed for jobsite slump adjustment.

Distribute load ticket to the project and keep one on file. The file copy needs to be readily available for inspection upon request. Issue a Form 116 for each load in the event a computer generated batch ticket cannot be provided.

Mixer Trucks

1. Truck Capacity
   a. Concrete Mixer – 63% of the total volume of the drum
   b. Concrete Agitator – 80% of the total volume of the drum

2. Inspected once a year

3. MSHA needs to be notified 7 days in advance of annual inspection and 2 days in advance of inspection of trucks added between annual inspections.

4. Certification Plate
   a. Gross volume of drum
   b. Mixer capacity
   c. Minimum and maximum mixer speeds

5. QC Technician needs to inspect trucks and keep a written report including the following inspection points
   a. Yearly inspection sticker
   b. Back up alarm – In working order
   c. Drum capacity – Rating plate
   d. Water valves – No leaks
   e. Water pump – No leaks
   f. Drum knuckle – No leaks
   g. Counters – Working
   h. Water glasses – clean
   i. Water gauge – clean
   j. Drum – No build up
   k. Blades – Not excessively worn or broken

6. Operate drums during transit at agitating speed only. Mixing during transit is prohibited.

7. Add at least 85 percent of design water requirement at the plant through the certified plant water meter.

8. Water for slump adjustment may be added at the plant through truck water system under the supervision of the certified concrete technician, provided the maximum specified water/cement ratio is not exceeded.

9. A maximum of 3 gal of water per cubic yard of concrete may be added at the point of discharge provided it does not exceed the maximum specified water/cement ratio.

10. No water may be added after partial discharge of the load.

11. Loading of mixers or agitators that contain wash water in the drum is prohibited.

12. When the concrete is specified or allowed to be produced by volumetric batching and continuous mixing, the batching and mixing unit shall meet C 685.

13. Calibration shall meet MSMT 558.

14. The minimum mixing time is 75 seconds for stationary mixers not subject to mixer performance tests.