



Concrete Basics: Fundamentals of Concrete

presented by Jake Vance, MCA's Director of Engineering – SE Mich.

Thursday, April 30, 2020

10:00 to 11:00 am Eastern

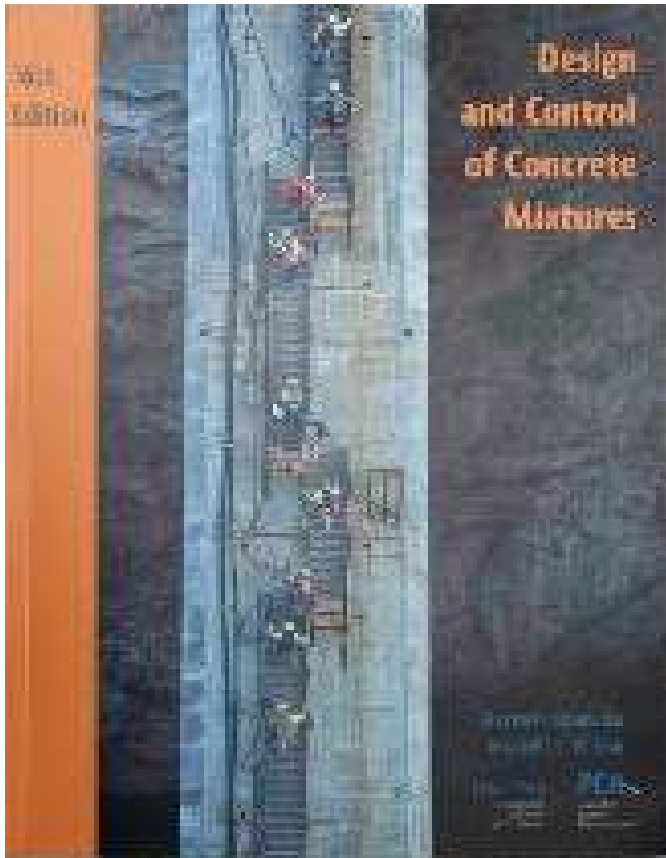
pdf handouts located at: <https://info.miconcrete.org/virtual-learning>

Outline

- Intro to Concrete
- Cement / Cementitious Materials
- Water
- Aggregates
- Admixtures
- Fiber Reinforcement



FUNDAMENTALS OF CONCRETE



Integrated Materials and Construction Practices for Concrete Pavement:

A State-of-the-Practice Manual

FHWA Publication No. HIF - 07 - 004

 U.S. Department of Transportation
Federal Highway Administration

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National Concrete Pavement
Technology Center



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Introduction

Concrete is a mixture of two components:

1. paste
2. aggregate

The paste (consisting of portland cement, supplementary cementitious materials, water and admixtures) binds the aggregate (sand and gravel or crushed stone) into a rocklike mass as the paste hardens due to a chemical reaction.

Concrete Materials



Sand is called **fine aggregate**.

Stone is called **coarse aggregate**.

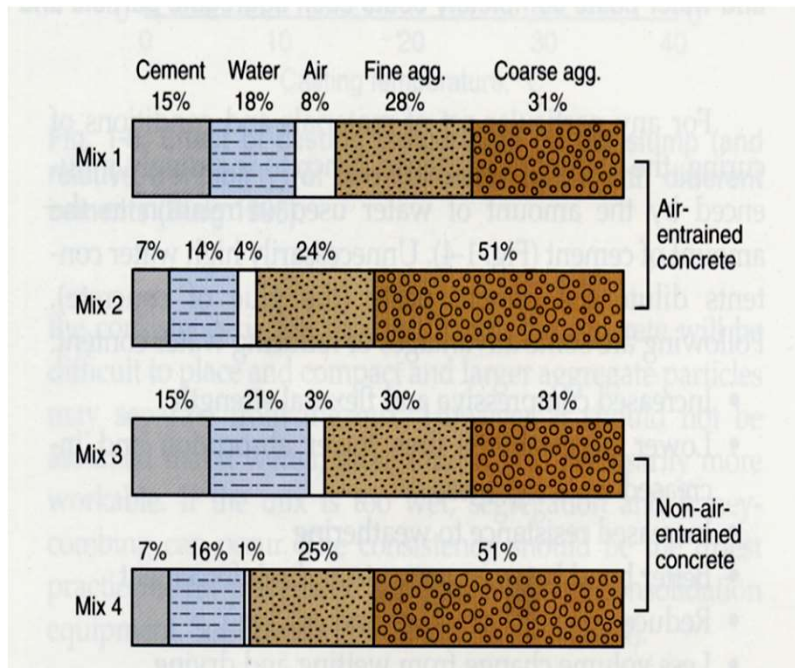
Supplementary cementitious materials typically include:

- fly ash
- slag cement
- silica fume

Chemical admixtures are added.

In addition, concrete mixes may also include fiber reinforcement.

Material Proportions



Concrete is batched and sold on the basis of volume

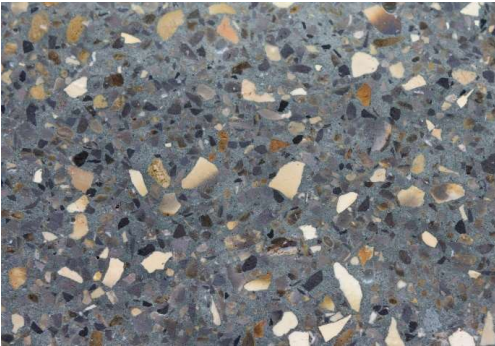
- yd³ or m³ (cubic meter)

Note: combination of fine and coarse aggregate represents 60-75% of the total volume

Concrete ≠ Cement



Although these two terms are often used interchangeably, they are not the same and have very different meanings.



Cement is a component material used to manufacture concrete. Concrete describes the finished product.

Portland Cements



Portland Cement



Portland cement is hydraulic - it sets and hardens when it comes into contact with water. The chemical reaction that occurs is called *hydration*.

In 1824 Joseph Aspdin (an English mason) filed the patent for portland cement.

When hardened, it resembled the color of a natural limestone quarried on the Isle of Portland in the English Channel.

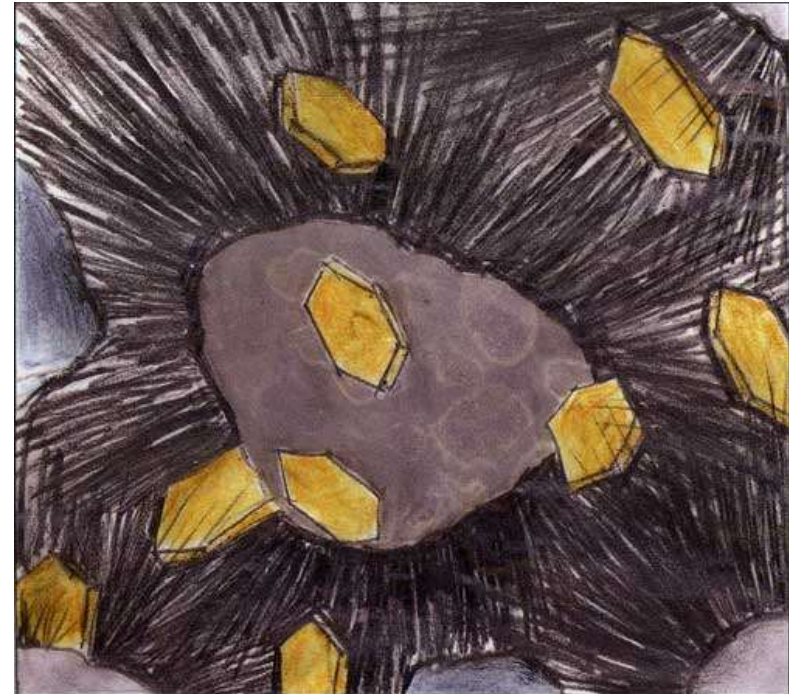
Hydration

- hydration begins immediately on contact and, over time, increases concrete strength
- it takes approximately 1/4 lb. of water to hydrate 1 lb. of portland cement
 - ratio of water to cement = 0.25
 - any water added above this amount is water of convenience used to facilitate the mixing and placing

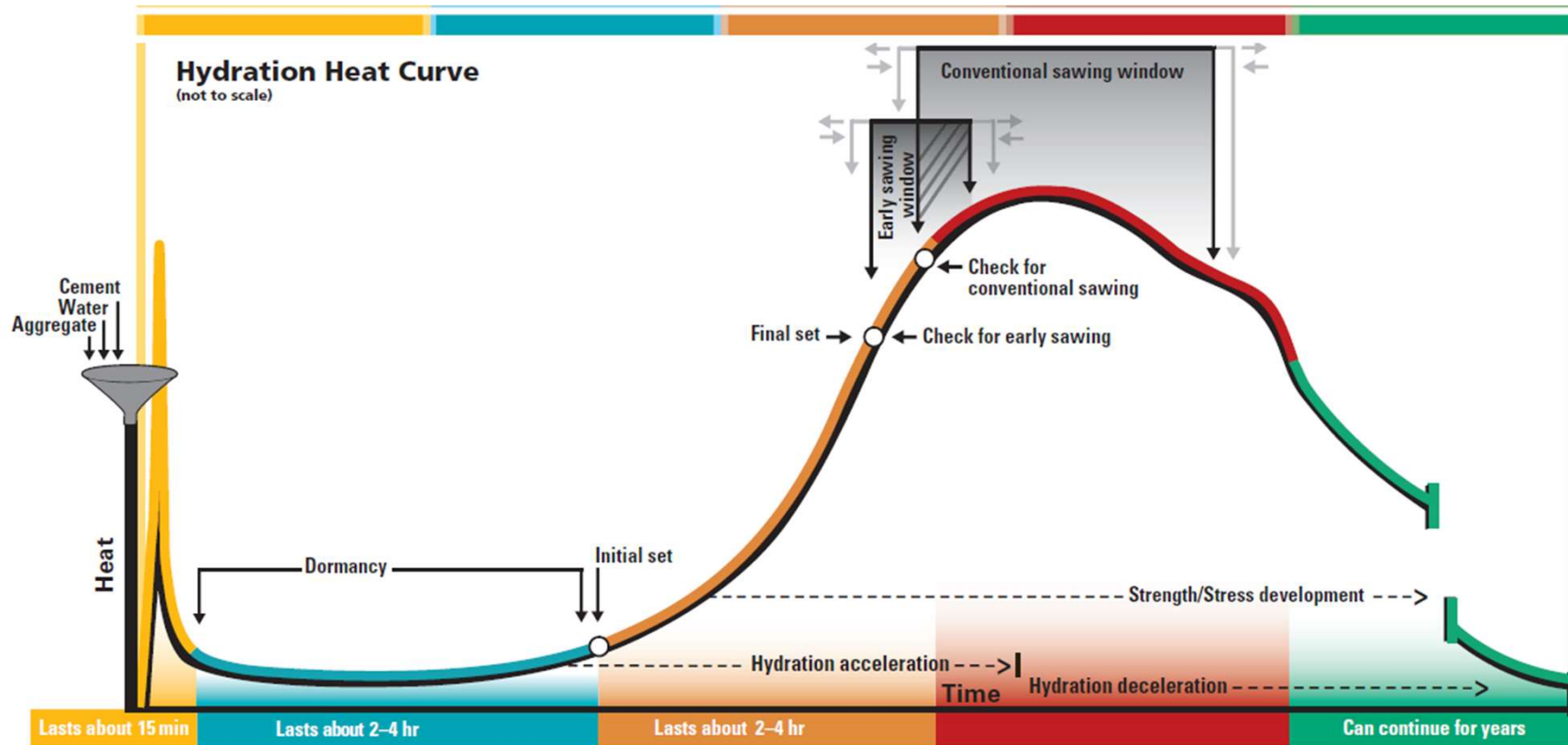


Hydration

- the cement particles form hairlike projections that mesh over time resulting in stiffening, hardening and strength development
- the chemical reaction is affected by ambient temperatures
 - warmer → faster
 - colder → slower
- the reaction ceases if the humidity level within the concrete drops below 80%



Heat of Hydration Curve



The Cement Manufacturing Process

To manufacture portland cement, you need the following raw material sources:

Lime ~ limestone, calcite, marl, shale

Iron ~ clay, iron ore

Silica ~ clay, marl, sand, shale

Alumina ~ aluminum ore, clay, fly ash, shale

"LISA"



Rotary Kiln



The raw materials are introduced into a rotary kiln and burned at a temperature between 2600-3000°F to produce clinker. The kiln is typically fueled by pulverized coal.

Cement Clinker



The burning of the raw materials results in a product called clinker. Clinker is predominantly the size of marbles but does vary in diameter.

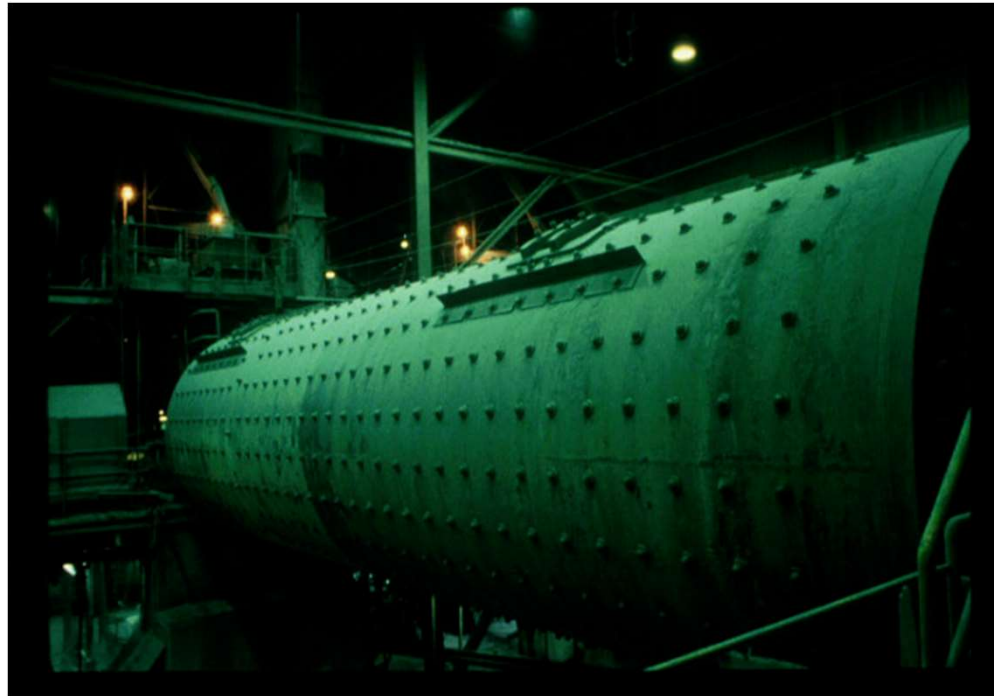
The Role of Gypsum



Gypsum is interground with the clinker to control the setting, drying shrinkage and strength gain properties of the cement.

~ 3-5% by mass

Finish Mill Grinding



Portland Cement



Classifications of Portland Cement

Different types of portland cement are manufactured according to ASTM C150 to meet various physical and chemical requirements.

<u>Type</u>	<u>Description</u>	<u>Percent</u>
I	general purpose	60-65%
II	moderate sulphate resistant	20-25%
III	high early strength	10-15%
IV	low heat	0%
V	sulphate resistant	< 1%

Supplementary Cementitious Materials



Supplementary Cementitious Materials

The practice of incorporating supplementary cementitious materials (SCMs) such as fly ash, slag cement and silica fume has grown significantly since the 1970's. Factors contributing to the growth include:

1. mix performance
2. environmental regulations
3. cost efficiencies

These materials may be used as *an addition to or as a partial replacement* for the portland cement depending on the properties of the materials and the desired effect on the concrete.

Supplementary Cementitious Materials

SCM's improve the fresh and hardened properties of concrete. Their chemical components are *similar* to those of portland cement.

- SCM's are byproducts of other industrial processes
- some SCM's are hydraulic, others are pozzolans

pozzolan: a material that reacts with cement and water to improve the properties of concrete

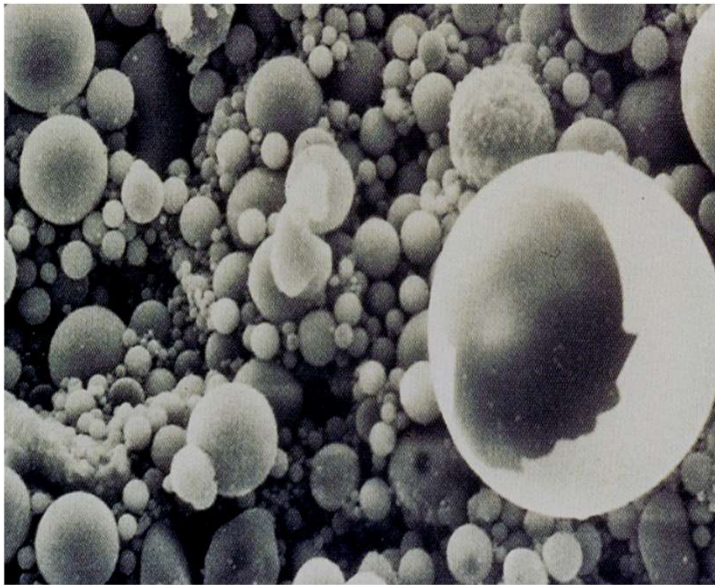
- more than 60% of all concrete mixtures contain a SCM

Fly Ash

Fly ash is the most commonly used SCM in concrete. It is the airborne residue from a coal combustion process such as an electric power generating plant (i.e. DTE Energy, Consumers Energy) that is collected from the flue gases by a variety of means.

- the use of fly ash in concrete dates back to the 1930's
- approximately 53 million tons is produced annually in the US with about 44% utilized
- all fly ashes are pozzolans, some are hydraulic

Fly Ash



- mineral impurities such as clay, quartz and shale in the coal melt and fuse together
- the fused material cools and solidifies into glassy spheres which are collected from the exhaust gases by scrubbers, electrostatic precipitators or fabric bag filters as a finely divided powder

Fly Ash



Fly ash must meet the requirements of ASTM C618.

Class C

- pozzolanic and cementitious
- high calcium, low carbon
- tan or buff in color
- ***replaces*** 15-40% of cement

Class F

- pozzolanic only
- low calcium, high carbon
- grey to black in color
- ***replaces*** 15-25% of cement

Slag Cement

Slag cement is the glassy material formed from molten slag produced in a blast furnace as a byproduct from the production of iron used in steel making. The molten slag (~ 2730 F) floats above the denser molten iron, is tapped from the furnace, then rapidly quenched with water to form a glassy sand-like material that is ground to a powder.

- when rapidly quenched with water, slag has cementitious properties
- when slowly cooled in air, it has no cementitious value and is typically used as an aggregate
- slag cement has been used in concrete for well over 100 years

Tapping of Molten Slag



Slag cement must meet the requirements of ASTM C989. When used for general purpose concrete, it typically *replaces* 30-50% of the portland cement.

Slag cement is classified by its level of strength reactivity when compared with portland cement as either grade 80, 100 or 120.

- grade 120 is the most reactive and yields the highest strength

Processing of Molten Slag



Silica Fume

Silica fume (also called microsilica or condensed silica fume) is a byproduct of producing silicon metals or ferrosilicon alloys. These metals are used in many industrial applications including aluminum and steel production, computer chip manufacturing and production of silicones that are used in lubricants/sealants.

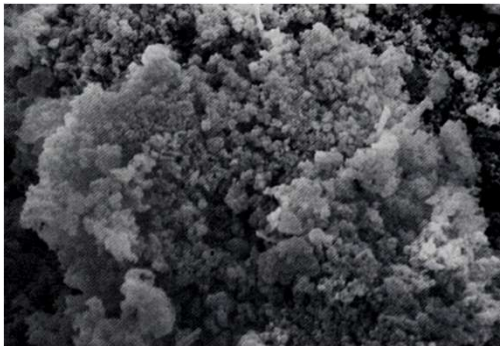
Silica Fume



Silica fume is the vapor that rises from electric arc furnaces used to reduce high purity quartz with coal. When it cools, it condenses and is collected in bag filters. A powder-like material, the color of silica fume ranges from grey to black. Silica fume is often used in projects where high strength or low permeability is required.

i.e. parking structures, bridge decks

Silica Fume



Silica fume must meet ASTM C1240. It is typically used at an *addition* rate of 5-10% by mass of the total cementitious materials content.

i.e. 600 lbs. total cementitious at 10% addition requires 60 lbs. of silica fume

Silica fume particles, like fly ash, are spherically shaped. It is extremely fine with particles approximately 100 times smaller than the average cement particle. It is a highly effective pozzolan.

SCM Effects Fresh Concrete

Table 3-7. Effects of Supplementary Cementitious Materials on Fresh Concrete Properties

	Fly ash		GGBF slag	Silica fume
	Class F	Class C		
Water requirements	↓ ↓	↓ ↓	↓	↑ ↑
Workability	↑	↑	↑	↓ ↓
Bleeding and segregation	↓	↓	↕	↓ ↓
Air content	↓ ↓ *	↓ ↓ *	↓	↓ ↓
Heat of hydration	↓	↕	↓	↔
Setting time	↑	↑	↑	↔
Finishability	↑	↑	↑	↕
Pumpability	↑	↑	↑	↑
Plastic shrinkage cracking	↔	↔	↔	↑

* Effect depends on properties of fly ash, including carbon content, alkali content, fineness, and other chemical properties.

Key:
 ↓ reduced
 ↓ ↓ significantly reduced
 ↑ increased
 ↑ ↑ significantly increased
 ↔ no significant change
 ↕ effect varies

SCM Effects Hardened Concrete

Table 3-8. Effects of Supplementary Cementitious Materials on Hardened Concrete Properties

	Fly ash		GGBF slag	Silica fume
	Class F	Class C		
Early strength	↓	↔	↓	↑↑
Long-term strength	↑	↑	↑	↑↑
Permeability	↓	↓	↓	↓
Chloride ingress	↓	↓	↓	↓
ASR	↓↓	↓↓	↓↓	↓
Sulfate resistance	↑↑	↑	↑↑	↑
Freezing and thawing	↔	↔	↔	↔
Abrasion resistance	↔	↔	↔	↔
Drying shrinkage	↔	↔	↔	↔

Key:

- ↓ reduced
- ↓↓ significantly reduced
- ↑ increased
- ↑↑ significantly increased
- ↔ no significant change
- ↕ effect varies



Mixing Water For Concrete

Acceptance Standard



Water that is potable (fit for human consumption) can be used in concrete without any testing or qualification.

Non-potable Water

Water that is non-potable (wells, streams, lakes or concrete operations) may still be used provided that additional testing has been conducted in accordance with ASTM C 1602.

Excessive impurities may impact set time, strength, corrosion of reinforcement and durability.

ASTM C 1602 Water Testing Criteria

Criteria	Limits	ASTM Test
7-day compressive strength, min., compared to control specimens	90%	C 109
Time of set, deviation from control specimens	Minus 60 minutes to Plus 90 minutes	C 191

Water, Cement, SCM's and the Water/Cement Ratio



The Water/Cement Ratio Law

"For given materials, the strength of the concrete (so long as we have a plastic mix) depends solely on the relative quantity of water as compared with the cement, regardless of mix or size and grading of aggregate."

Duff A. Abrams, 1918



Water/Cement Ratio

The water/cement ratio is calculated by dividing the weight (mass) of water by the weight (mass) of cement or combined cementitious materials in a given volume or batch size of concrete (i.e. 9 yd³).

- abbreviated as w/c or w/cm
 - water/cement ratio has no units
 - reported to the nearest 2 decimals i.e. 0.48
 - includes plant added and site added water
 - must include fly ash, slag cement and silica fume as cementitious (cm) materials in calculation
 - water is stated in lbs. or gallons, cement in lbs. or bags
- 1 gallon = 8.33 lb. (round answer to nearest lb.) 1 bag = 94 lbs.

Example Calculation

batch size = 5 yd³

portland cement – type I 2000 lbs

fly ash – class C 800 lbs

batch water 1400 lbs

coarse aggregate (SSD) 8500 lbs

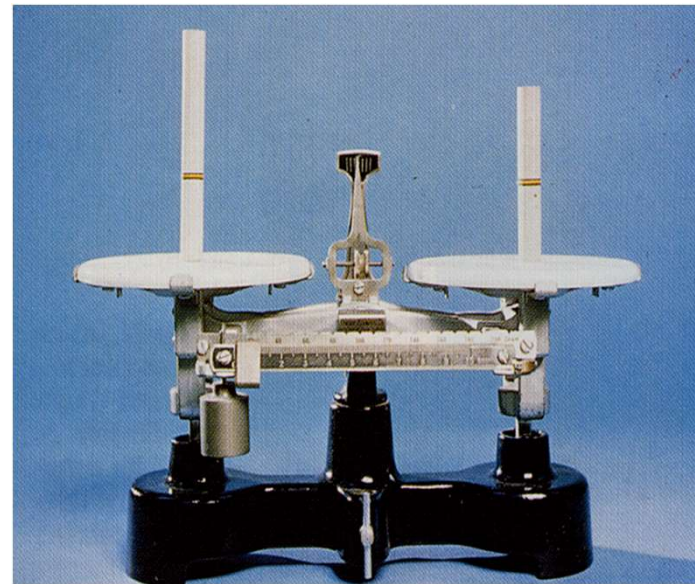
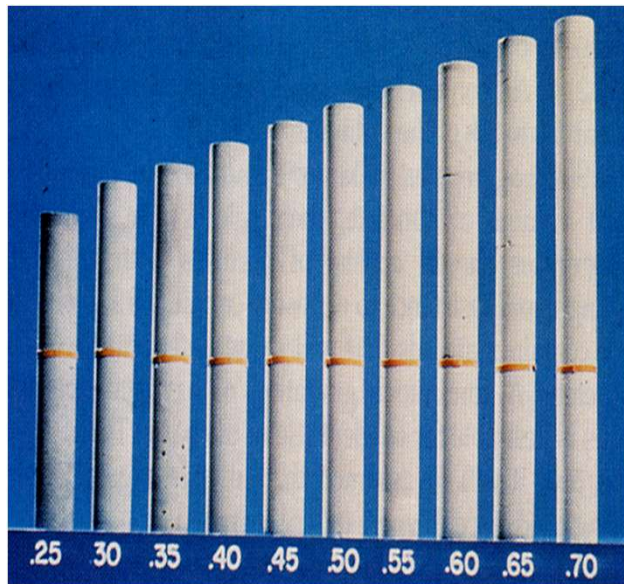
fine aggregate (SSD) 6500 lbs

$$w/cm = 1400 \text{ lbs.} \div (2000 \text{ lbs.} + 800 \text{ lbs.})$$

$$= 1400 \text{ lbs.} \div 2800 \text{ lbs.}$$

$$= 0.50 \text{ (no units)}$$

Effect of Excessive Water



Water Content vs Fresh Concrete Properties



Concrete placed at a high water content (w/c ratio) will exhibit the following characteristics in the unhardened (fresh) state:

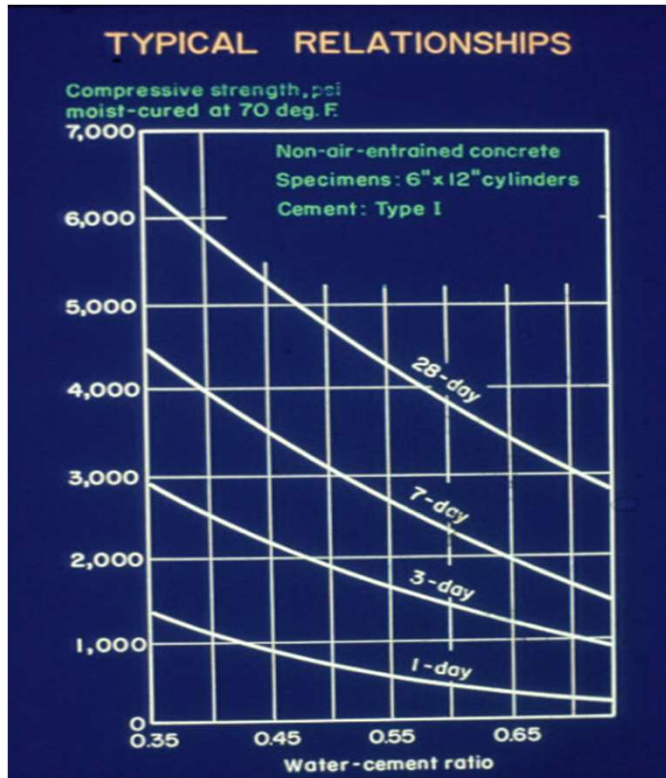
1. segregation of aggregate

- during discharge and in-place

2. increased bleeding

- the migration of water to the surface caused by the settlement of the solid materials

Water Content vs Hardened Concrete Properties



The quality of the hardened concrete is strongly influenced by the amount of water in relation to the amount of portland cement or combined cementitious materials.

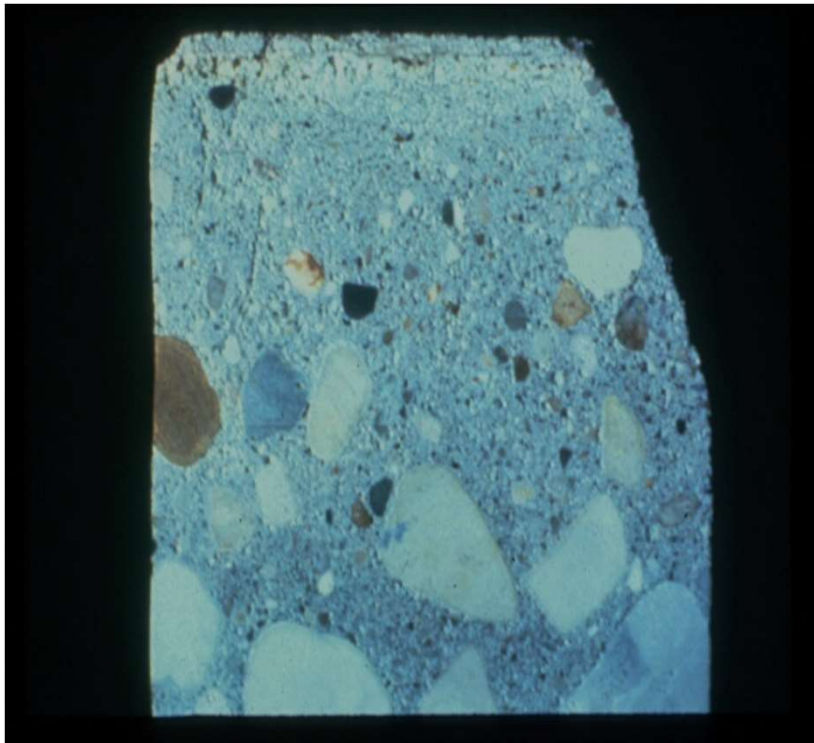
Compressive strength decreases as the water content increases!

Water Content vs Hardened Concrete Properties

In addition to decreasing the strength of the mix, concrete placed at a high water/cement ratio will result in:

1. increased permeability
2. decreased resistance to freezing/thawing
3. an increased number of drying shrinkage cracks
4. reduced bond between concrete and reinforcement

Water Content vs Hardened Concrete Properties



Characteristics of hardened concrete placed at a high water content include:

1. segregation of aggregate
2. color variation from top to bottom
 - lighter at the top
3. defined plane of potential delamination just beneath the surface

Recommended W/C Ratios

Exposure Condition	Max. w/cm ratio	Min. f'_c (psi)
Low permeability when exposed to water	0.50	4000
Subject to freezing/thawing when moist or to deicing chemicals	0.45	4500
Corrosion protection of reinforcement from chlorides, deicing chemicals, salt water, seawater	0.40	5000

Slump vs. Water Content



The slump test was developed to measure the consistency of the concrete from load to load. It can be an indicator of the amount of water in the mix but other factors, such as the presence of chemical admixtures, need to be considered.

Water/Cement Ratio Summary

w/c ratio ↑ strength ↓

w/c ratio ↓ strength ↑

The benefits of maintaining the lowest practical w/c ratio include:

- increased durability
- lower permeability
- reduced shrinkage cracking

Aggregates for Concrete



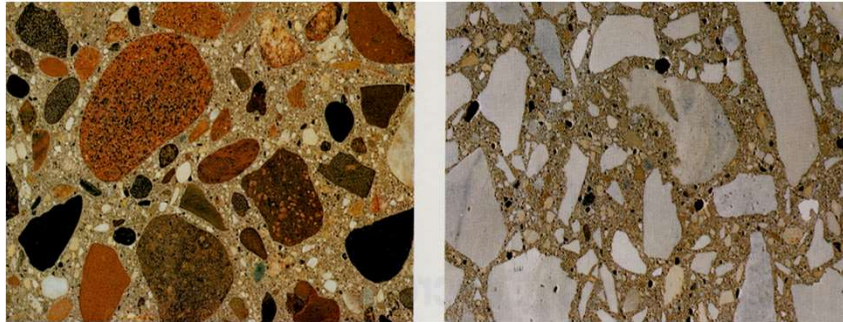
Fine and Coarse Aggregate



Aggregates occupy 60-75% of the concrete volume.

- aggregates can be natural (riverbed/gravel), manufactured (crushed stone) or recycled concrete
- normal weight aggregates must meet ASTM C33 - bulk density 75-110 lb/ft³
- lightweight aggregates must meet ASTM C330 - bulk density < 75 lb/ft³
- #4 sieve distinguishes between fine and coarse aggregate
- aggregates must be well graded
- aggregates must consist of clean/washed, hard, durable particles free of materials that could affect hydration and bond of the cement paste

Coarse Aggregate Natural vs. Crushed



Natural - River Gravel

- small % crushed
- rounded particles
- *increases* workability
- interior applications

Crushed - Limestone

- entirely crushed
- angular particles
- *decreases* workability
- aggregate interlock, bond to paste
- exterior applications

Grading of Aggregates



Grading is a measure of the size distribution of aggregate particles determined by passing aggregate through sieves of different sizes. The results are compared to ASTM C33 and MDOT specifications.

Since aggregate is more chemically and dimensionally stable than cement paste, it is important to maximize the amount of aggregate in the mix.

Grading of Aggregates

Well-graded aggregates are preferred because the smaller particles fill the voids between the larger particles thereby maximizing aggregate volume.

The result optimizes the amount of cement in the mix, minimizing the amount of water that is necessary to coat the aggregate and fill the remaining voids. This benefits long term durability by increasing strength and decreasing permeability.

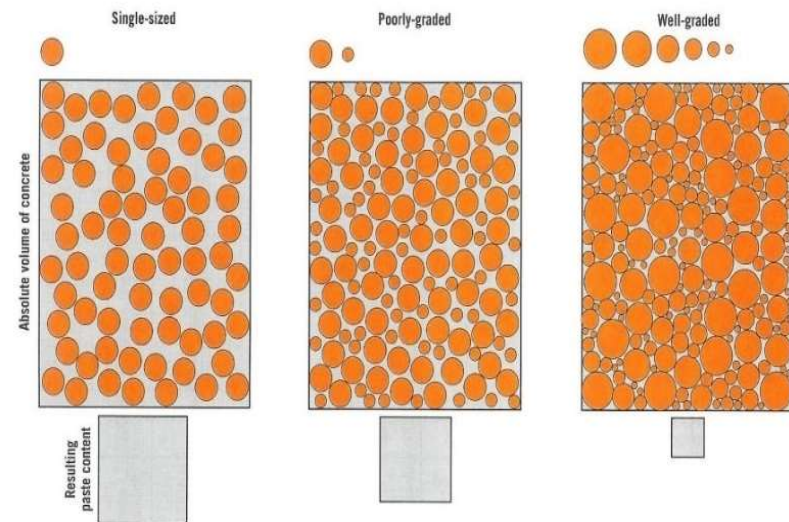


Figure 6-13. For equal absolute volumes when different sizes are combined, the void-content decreases, thus the necessary paste content decreases.

Grading of Aggregates

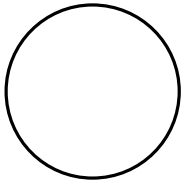


The use of gap-graded aggregate (a deficiency in certain sizes) results in mixtures that segregate and require more water.

Very fine sands increase water demand while very coarse sands typically produce harsh mixes that are difficult to finish.

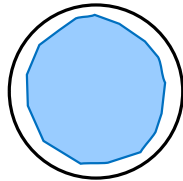
Aggregate Moisture Conditions

oven dry



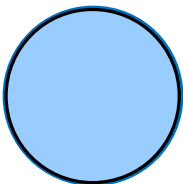
no moisture

air dry



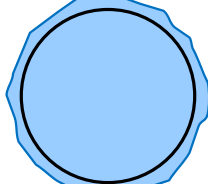
less than
potential
absorption

SSD



equal to
potential
absorption

wet

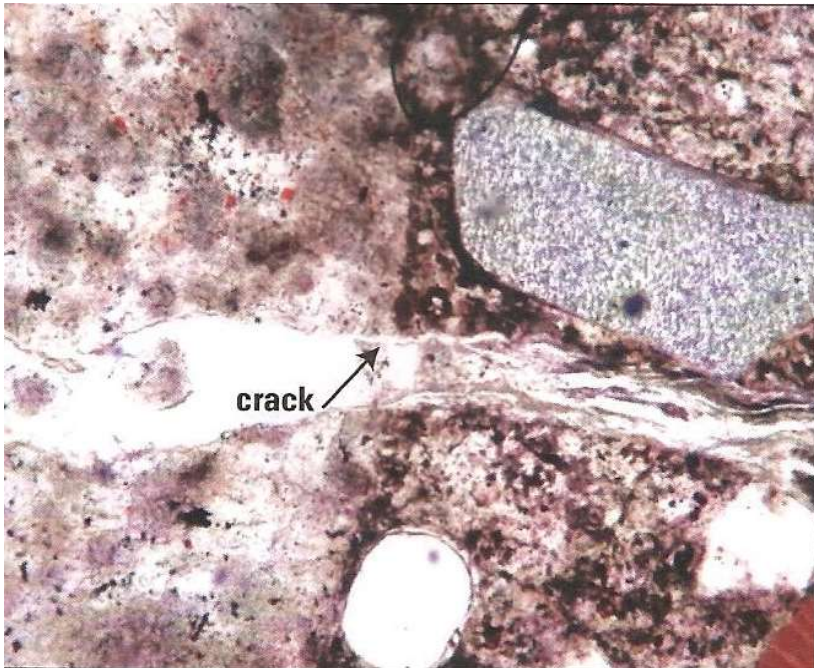


greater
than
absorption

Aggregates have an internal void or pore structure that at any time may or may not contain water (absorbed water). Depending on the moisture content, the four possible conditions are as follows:

1. **oven dry** - no moisture present (only attainable in lab)
2. **air dry** - dry at surface, capable of absorbing additional water
3. **saturated-surface dry (SSD)** - fully saturated, neither absorbs nor contributes water to the mix
4. **wet** - contains an excess amount of surface moisture

Aggregate Durability: ASR



Some aggregates contain certain minerals that can react with the alkalis in cement to form a gel that expands when exposed to moisture. The result of this reaction (alkali-silica reactivity or ASR) is cracking in the aggregate and concrete.

Some specifications (e.g. MDOT) require testing fine aggregate (sand) for this.

Aggregate Popouts



A popout is a conical fragment that breaks out of the concrete surface, leaving a void or shallow depression behind. Popouts result from deleterious materials in aggregate such as chert, lignite and shale that are soft, porous and highly absorptive that when subjected to cycles of freezing/thawing or wetting/drying fracture or spall from the surface.

- ASTM and MDOT specifications limit the amount of deleterious material

A photograph showing a concrete pouring operation. A metal chute is angled from the upper left, pouring a thick, dark grey concrete mixture into a large, rectangular form. The concrete is being poured onto a white plastic liner that covers the bottom of the form. The concrete has a coarse, aggregate-rich texture. In the background, another section of the form is visible, already filled with concrete, and a person's legs and boots are partially visible, standing on the concrete. The overall scene is a construction site for a concrete slab.

Admixtures for Concrete

Admixtures for Concrete

A material other than water, aggregates, portland cement, supplementary cementitious materials and fiber reinforcement that is added to the concrete mixture immediately before or during mixing to modify the fresh or hardened concrete properties .

The four most common admixture classifications are:

1. air entraining
2. accelerating
3. retarding
4. water-reducing

Admixture Specifications



Admixtures must meet the following ASTM specifications:

1. C260

- air entraining

2. C494

- water reducing
- retarding
- accelerating

Why Air Entrained Concrete...

Concrete that is exposed to cycles of freezing and thawing while in a saturated condition must be air entrained. The microscopic entrained air voids provide a source of internal pressure relief as ice crystals form in the pores and capillaries of the concrete.

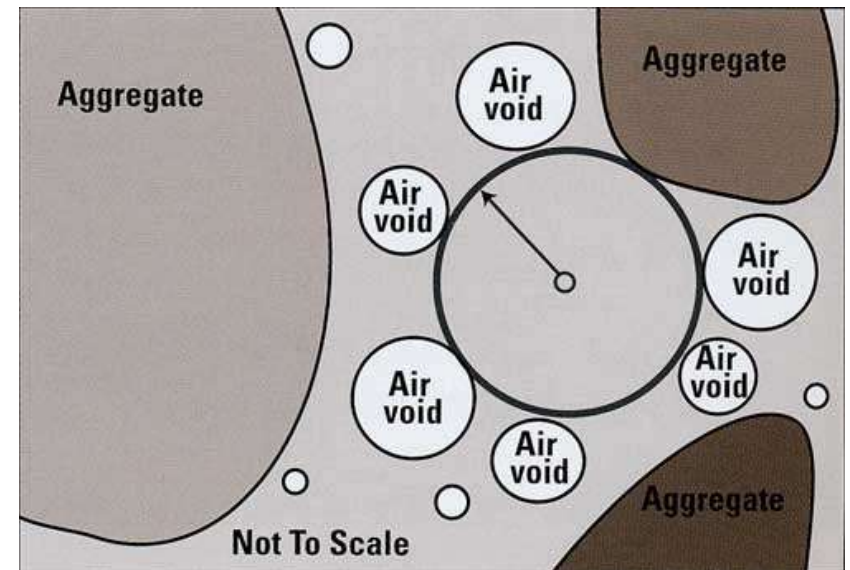
The development of air entrained concrete can be traced back to the 1930's.



Air Entrained Concrete

Air entrained concrete can be produced in one of two ways:

1. using an air entrained cement (Type IA)
2. adding an air-entraining admixture during batching
 - millions of tiny bubbles created by mixing are stabilized by a soap-like coating
 - air entraining admixtures are measured by ounces per hundred weight of cement or combined cementitious material - oz/cwt



Entrained vs Entrapped Air

Entrained air bubbles are bubbles that are stabilized as a result of introducing an air entraining admixture into the concrete. The bubbles are extremely small (0.01 to 1.0 mm in diameter), are randomly distributed and not interconnected.

Entrapped air bubbles form in concrete as a result of mixing, handling and placing and are largely a function of aggregate characteristics. The bubbles are usually 1.0 mm in diameter and larger.

Note: 1 inch = 25 mm

Air Entrained vs Non-Air Entrained Concrete



Air Entrained Concrete

Advantages

The primary function of air entrained concrete is freeze/thaw durability. Other advantages of having air in concrete include:

- reduced segregation and bleeding
- reduced water demand
- improved mix pumpability
- reduced permeability

Strength Impact

Generally, for every one percent entrained air beyond the design value, concrete losses 3-5% of its compressive strength.

Percent Volume of Air

Testing criteria:

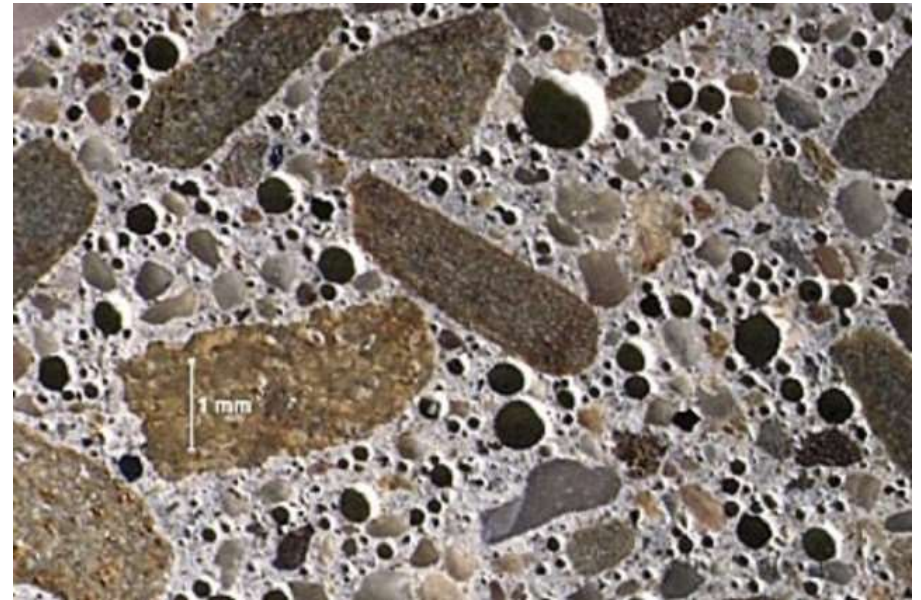
Typical spec: $6.5 \pm 1.5\%$

MDOT specs:

action limits: <5.5 or >8.5

suspension limits: <5.0 or >9.0

Total air = entrapped + entrained



Factors Affecting Air Content

Based on a fixed dosage comparison i.e. 1.0 oz/cwt

- | | |
|---------------------|---|
| 1. cement | - air content ↓ as cement content ↑ |
| 2. coarse aggregate | - air content ↑ as max. aggregate size ↓ |
| 3. fine aggregate | - air content ↑ as % fine aggregate ↑ |
| 4. mix water/slump | - air content ↑ as slump ↑ (up to 7 inches) |
| 5. temperature | - air content ↓ as temperature ↑ |
| 6. mixing time | - air content ↓ with extended mix times |
| 7. vibration | - air content ↓ as vibration time ↑ |

Accelerating Admixtures

Accelerating admixtures are used to accelerate the rate of hydration (setting) and strength development of concrete at an early age. They are typically used during cold weather.

- the most common accelerator is calcium chloride
 - inexpensive
 - is not an anti-freeze agent
 - dosage up to 2% by weight of cement or cementitious material
- non-chloride accelerators *must* be used when concrete contains reinforcing steel and moisture is present during service due to the risk of corrosion

Retarding Admixtures

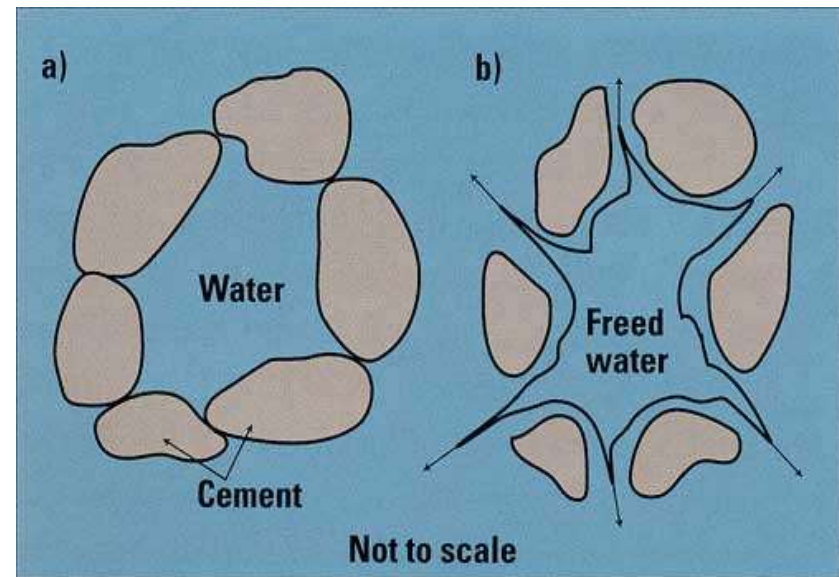
Retarding admixtures are used to delay the setting or hardening rate of concrete. They will not decrease the initial concrete temperature. They are typically used during hot weather to:

- offset the accelerating effect on setting
- delay the set of concrete for difficult or unusual conditions of placement such as for large piers and foundations or pumping concrete over considerable distances
- delay the set for special finishing techniques (i.e. exposed aggregate finishes) or anticipating long transport times

Water Reducing Admixtures

Water reducing admixtures are cement dispersing agents that were developed to improve the efficiency of the available mix water in the concrete. They function by applying surface charges on the agglomerated cement particles resulting in:

1. A reduction in the mix water required to produce concrete of a given slump.
2. An increase in slump without changing the design water content.



Water Reducing Admixtures

The three classifications of water reducing admixtures (WRA) are:

1. type A - conventional
 - 5-10% water reduction
2. mid-range
 - 6-15% water reduction
3. type F/G - high range
 - known as superplasticizers
 - 12-30% water reduction

Note: Certain WRA's may increase the air content of the mix.



Fiber Reinforcement



Fiber Reinforcement

Fibers are manufactured from steel, plastic, glass and other natural materials (wood cellulose).

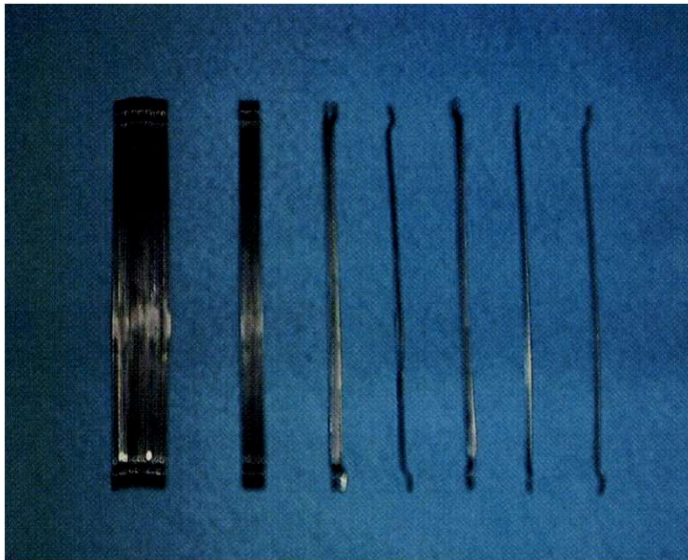
- available in a variety of shapes, sizes and thicknesses
- may be round, flat, crimped or deformed with lengths from ¼ inch to 6 inches
- added to concrete in low volume dosages (often less than 1%)
- provide secondary reinforcement
- depending on fiber type can improve impact resistance, abrasion resistance, early stage crack resistance, toughness

Synthetic Fibers



- Man-made fibers consisting of nylon, polyester, polyethylene, polypropylene, etc.
- polypropylene is the most common fiber type
 - dosages range from 1.5 to 5.0 lb/yd³
 - useful in reducing early age shrinkage and subsidence cracking
 - common in concrete overlays
 - synthetic fibers are an alternative to welded wire mesh

Steel Fibers



Steel fibers are short, discrete lengths of steel of any number of cross sections.

- most common application is for industrial floors
- typical dosage is 25-50 lb/yd³
- may be used for shotcrete, bridge decks, airport runways, and highway pavements
- surface corrosion is cosmetic as opposed to a structural concern

Summary

4 Basic Ingredients in Concrete:

- Cement / Cementitious Materials
- Water
- Aggregates
- Admixtures

Questions?

jvance@miconcrete.net

517-230-2322

ALSO, PLEASE SEND SUGGESTIONS
FOR ADDITIONAL CONCRETE WEBINAR TOPICS!

For the current webinar schedule:

<https://info.miconcrete.org/virtual-learning>

