MICHIGAN CONCRETE ASSOCIATION

# 2021 MCA Winter Webinars

Brought to you by:

SUPERIOR MATERIALS

LEVY SOLUTIONS FOR YOUR ENVIRONMENT®

ST MARYS

MICHIGAN CONCRETE ASSOCIATION

# Concrete Basics: Fundamentals of Concrete

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

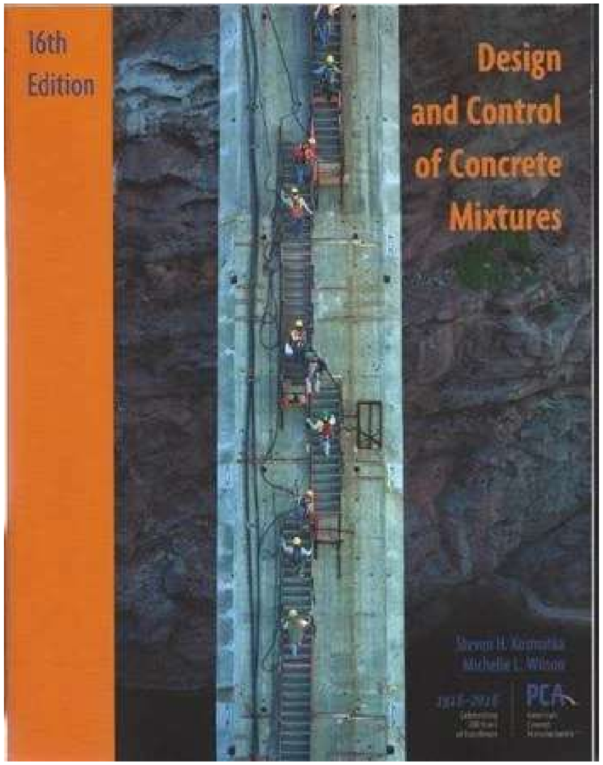
Thursday, January 28, 2021 10:00 to 11:30 am Eastern

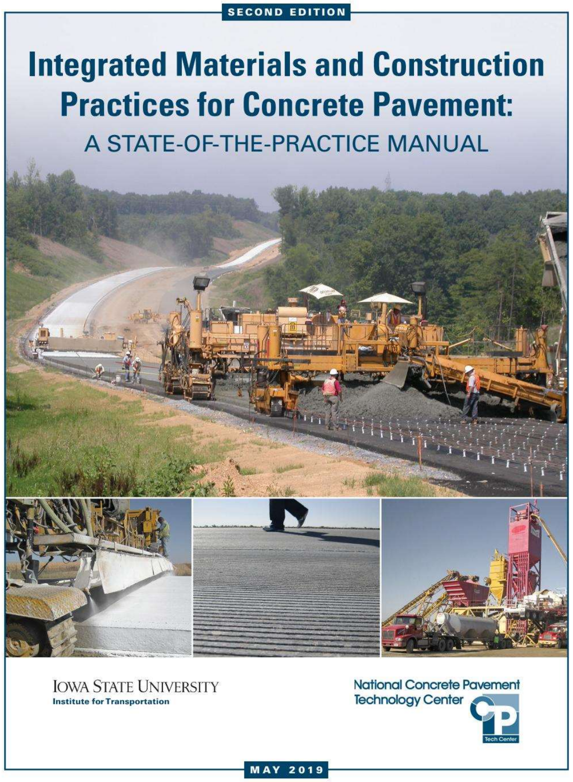
pdf handouts located at: https://www.miconcrete.org/annual-conference

# Outline

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

# FUNDAMENTALS OF CONCRETE




MICHIGAN CONCRETE ASSOCIATION

# 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

**Paste Materials**

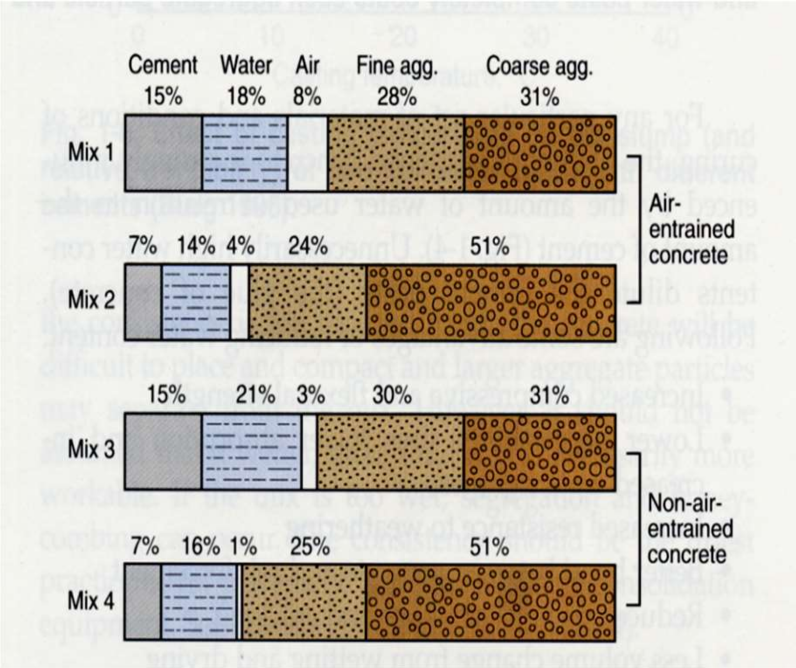
- Portland Cement
- Supplementary Cementitious Materials (SCM's)
  - Typically fly ash, slag cement or silica fume
- Water
- Potential Chemical Admixtures
  - air entraining, accelerators, retarders, water reducers

**Aggregate Materials**

- Sand is called **fine aggregate.**
- Stone is called **coarse aggregate.**

*Concrete mixes may also include fiber reinforcement.

# Material Proportions

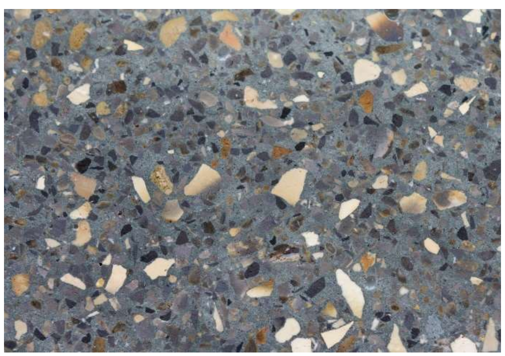



Concrete is batched and sold on the basis of volume

- $yd^3$ or $m^3$ (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

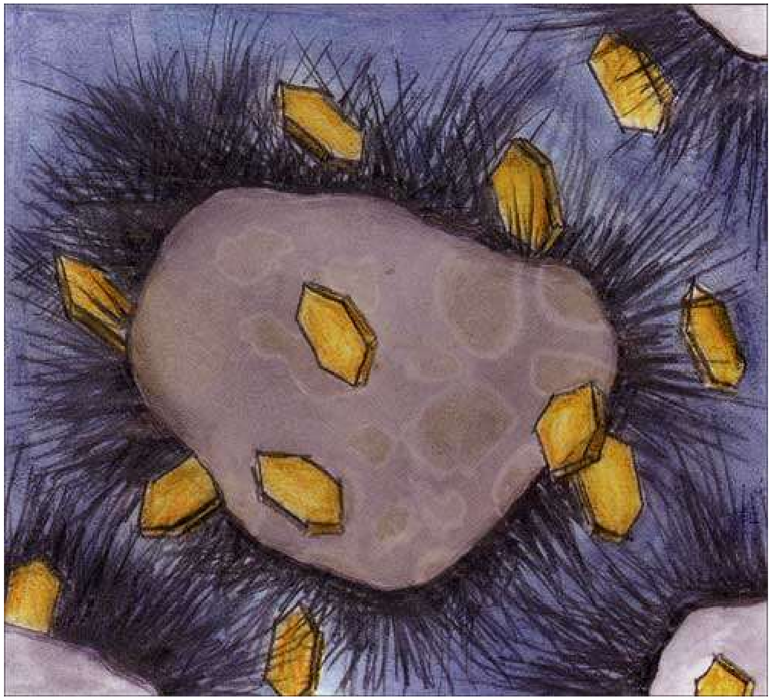
Portland cement is hydraulic - it sets and hardens when it comes into contact with water. The chemical reaction that occurs is called ***hydration***.

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

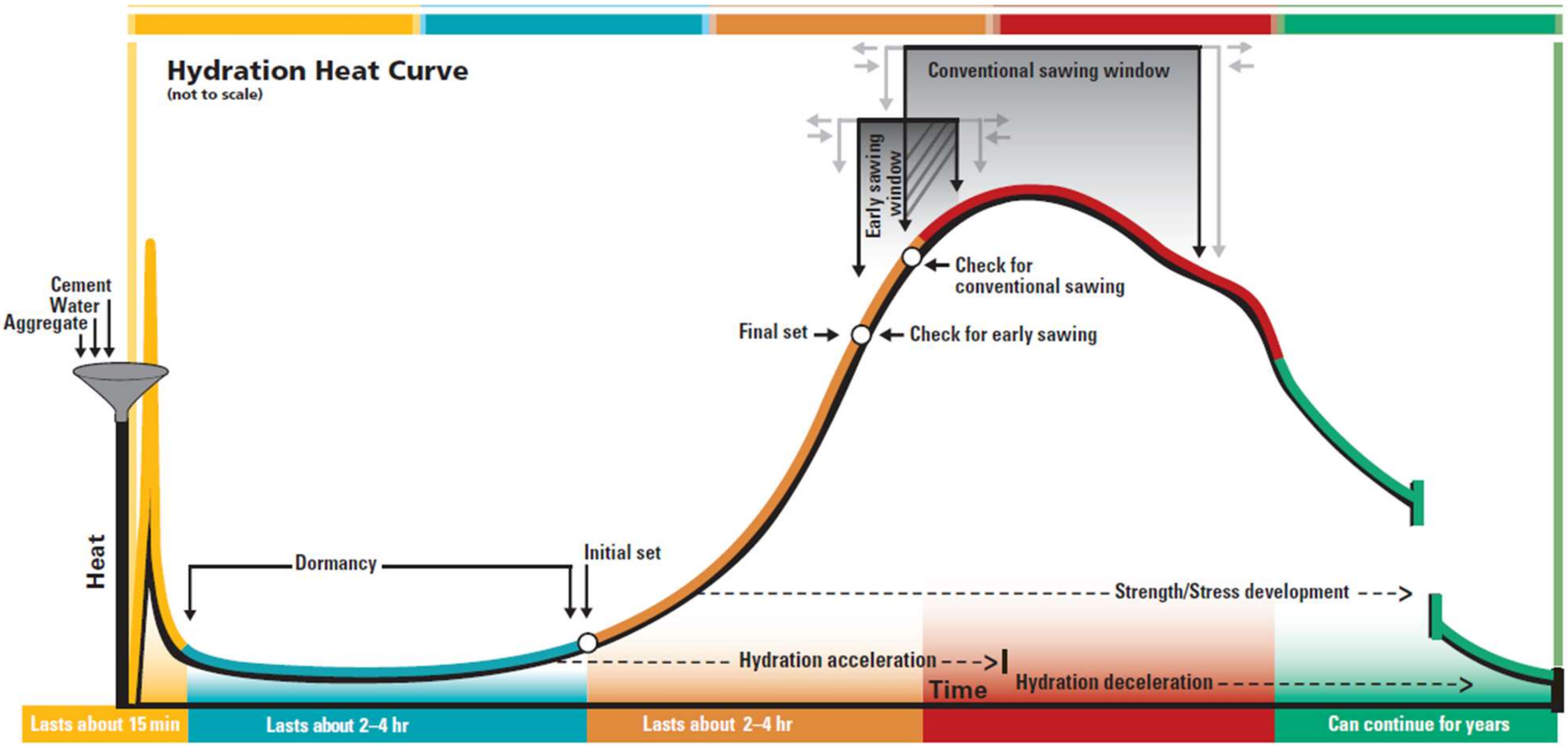
- hydration begins immediately on contact and, over time, increases concrete strength
- it takes approximately 1/4 lb. of water to hydrate 1 lb. of portland cement
  - ratio of water to cement = 0.25
  - any water added above this amount is water of convenience used to facilitate the mixing and placing



# 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.

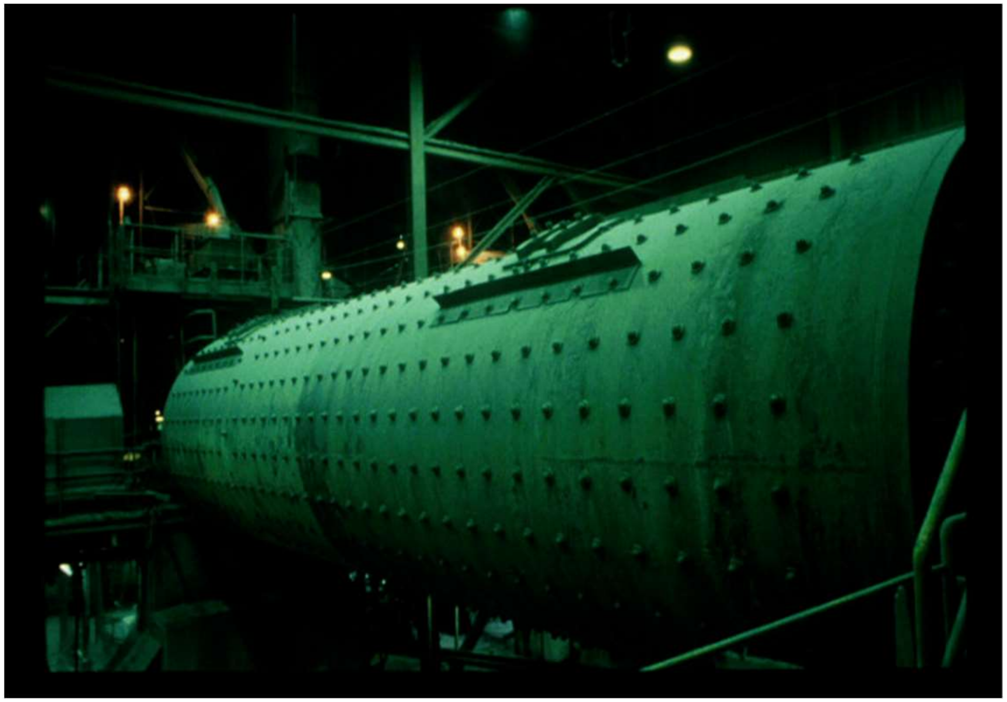
Clinker is predominantly the size of marbles but does vary in diameter.

# 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.

| Type | Description | Percent |
|---|---|---|
| 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 (SCM's)

# 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

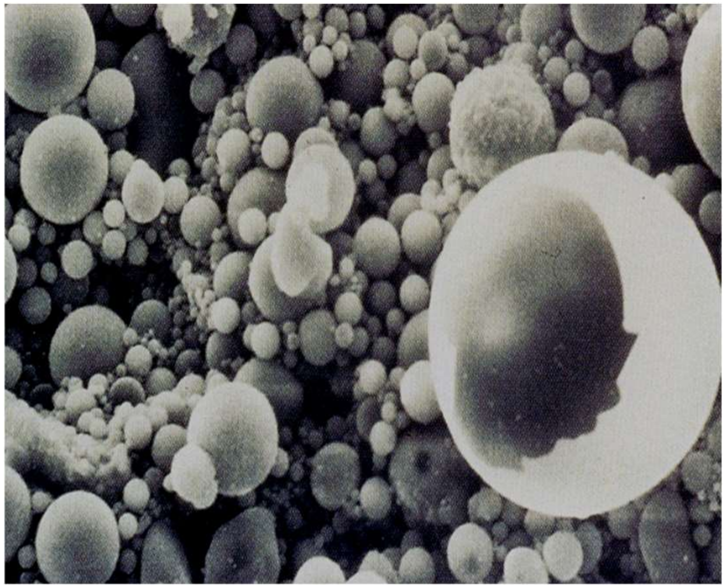
- more than 60% of all concrete mixtures contain a SCM

# 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

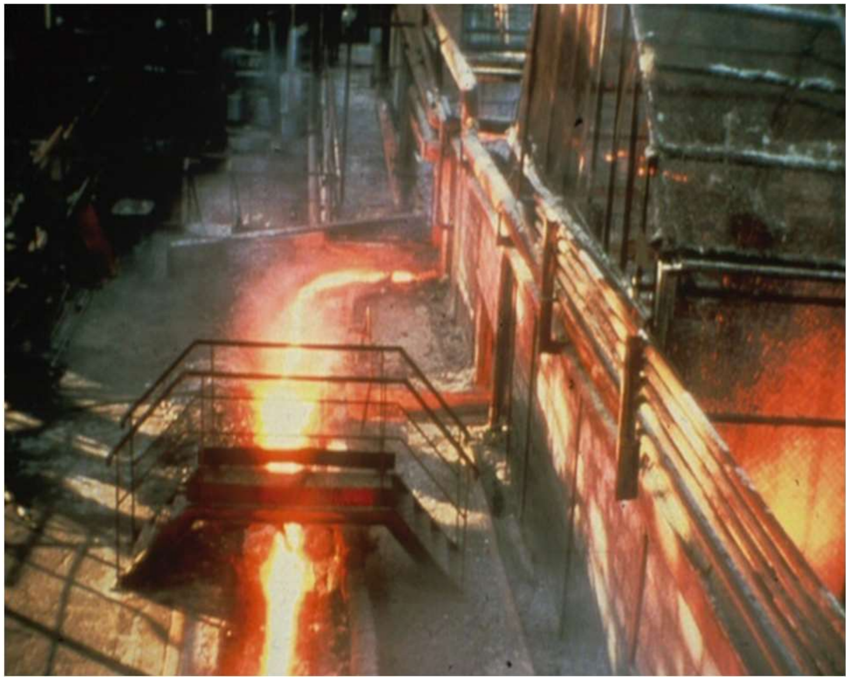
**Class F**
- pozzolanic only
- low calcium, high carbon
- grey to black in color
- ***replaces*** 15-25% of cement

# 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

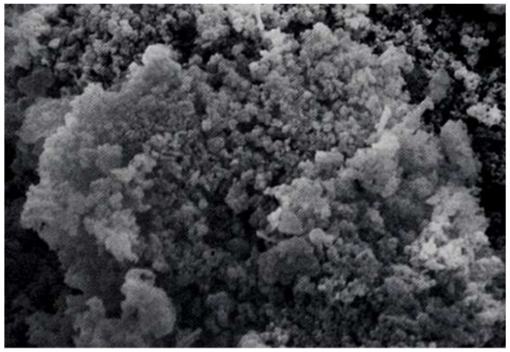
Silica fume (also called microsilica or condensed silica fume) is a byproduct of producing silicon metals or ferrosilicon alloys. These metals are used in many industrial applications including aluminum and steel production, computer chip manufacturing and production of silicones that are used in lubricants/sealants.

# 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 | | | |
|---|---|---|---|---|
| | Class F | Class C | GGBF slag | Silica fume |
| 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 $yd^3$).

- 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.

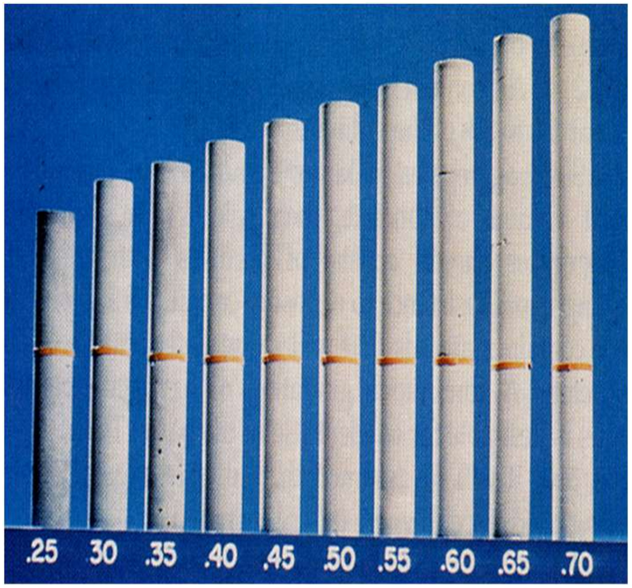
# Example Calculation

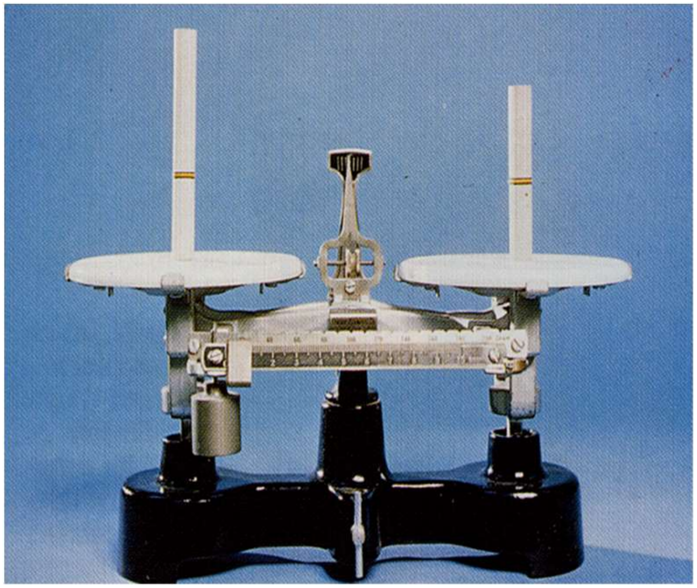
batch size = 5 $yd^3$

| | |
|---|---|
| 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 lbs. ÷ (2000 lbs. + 800 lbs.)
= 1400 lbs. ÷ 2800 lbs.
= 0.50 (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:

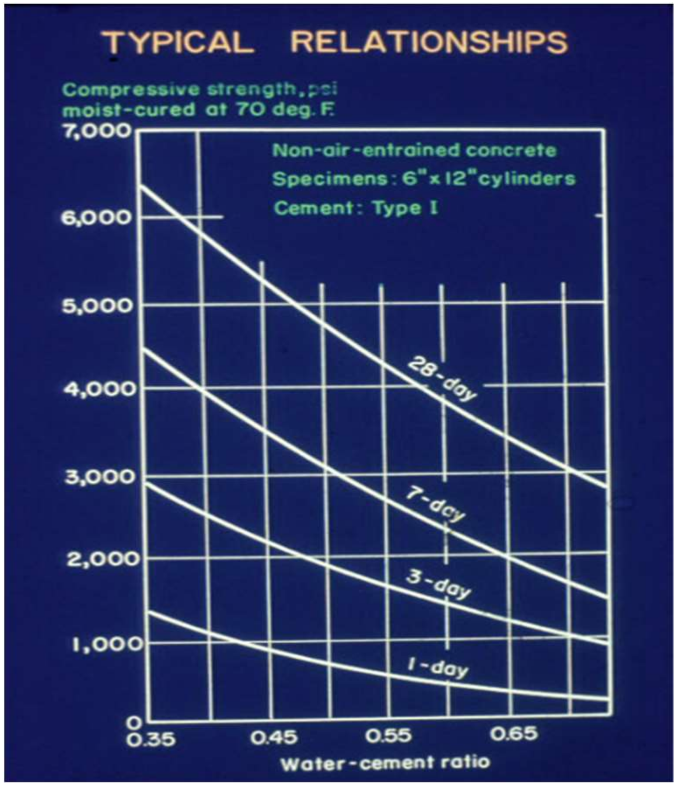
1. segregation of aggregate

- 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.

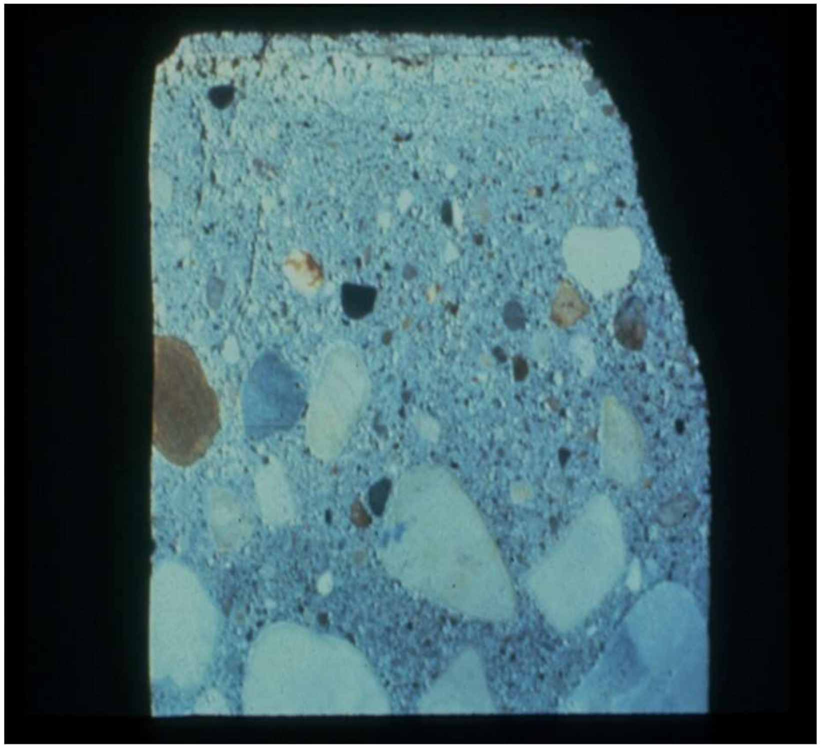
**Compressive strength decreases as the water content increases!**

# 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

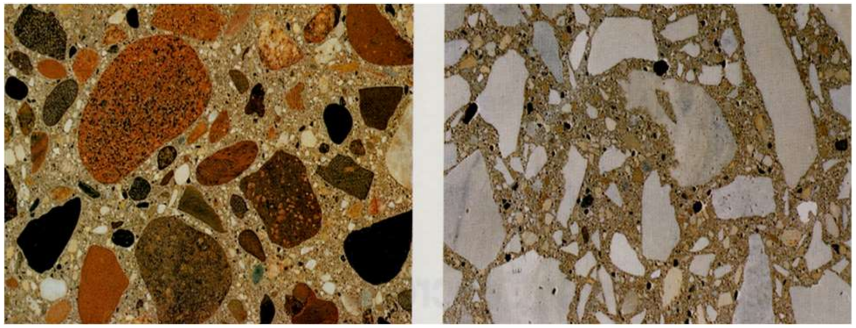

Aggregates for
Concrete

# 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/ft$^3$
- lightweight aggregates must meet ASTM C330 - bulk density < 75 lb/ft$^3$
- #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.

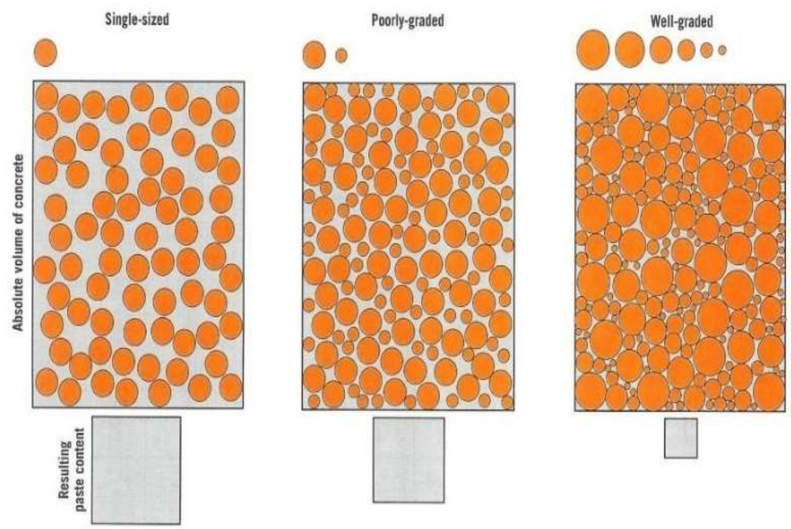


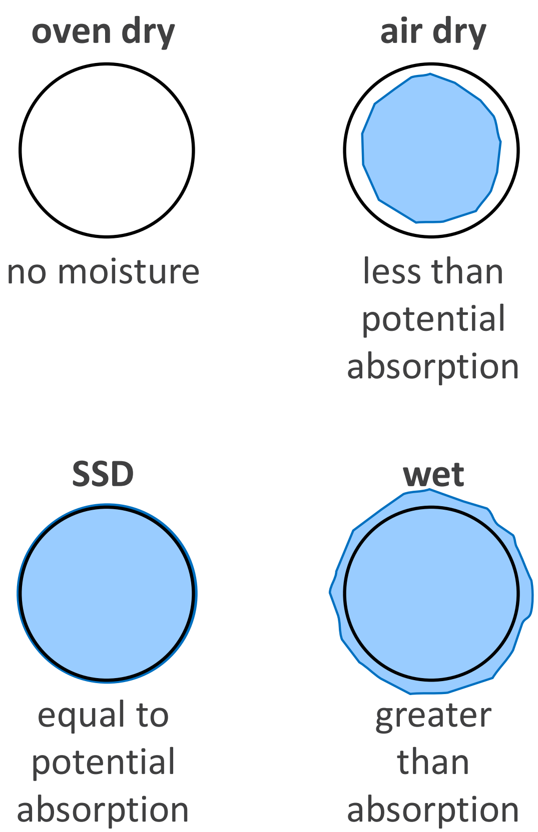

Figure 6-13. For equal absolute volumes when different sizes are combined, the void-content decreases, thus the necessary paste content decreases.

# 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.

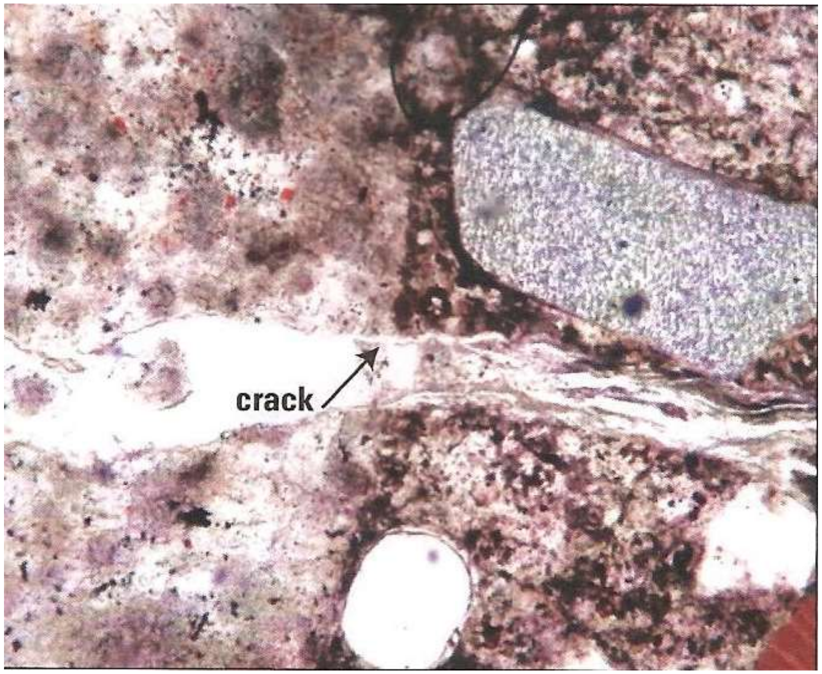
# Aggregate Moisture Conditions




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 Durability: ASR

# 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


Admixtures for Concrete

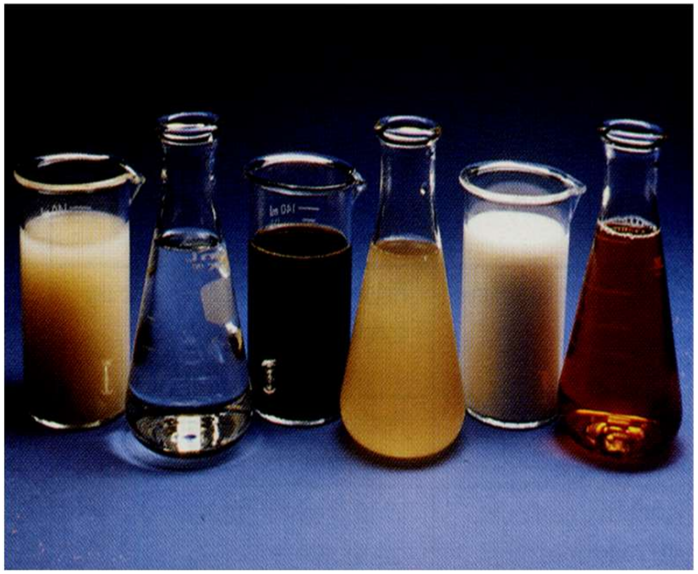
# Admixtures for Concrete

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…

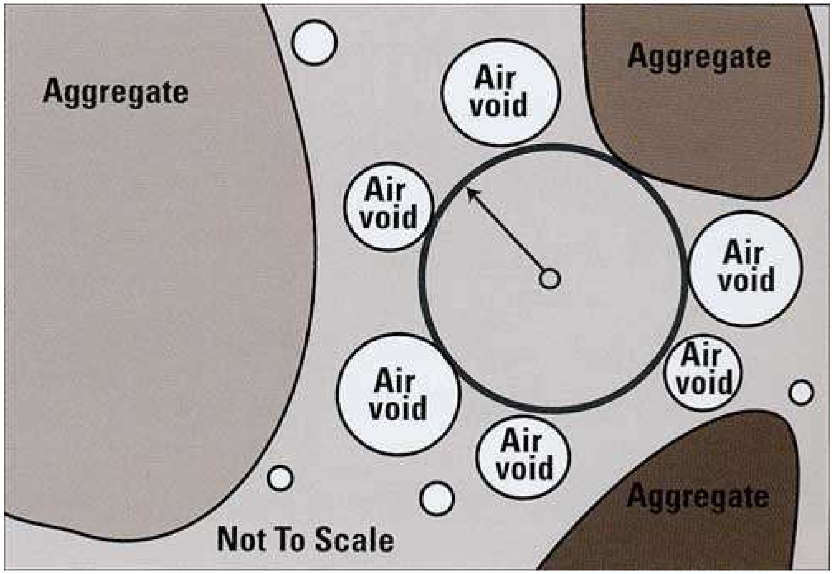
Concrete that is exposed to cycles of freezing and thawing while in a saturated condition must be air entrained. The microscopic entrained air voids provide a source of internal pressure relief as ice crystals form in the pores and capillaries of the concrete.

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 dishsoap soap-like coating
   - air entraining admixtures are measured (or dosed) 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 all 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. Does not assist in freeze-thaw

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

Design Criteria

Total Air = 6% (Michigan)

Testing criteria:

Typical spec: 6.5 +/- 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

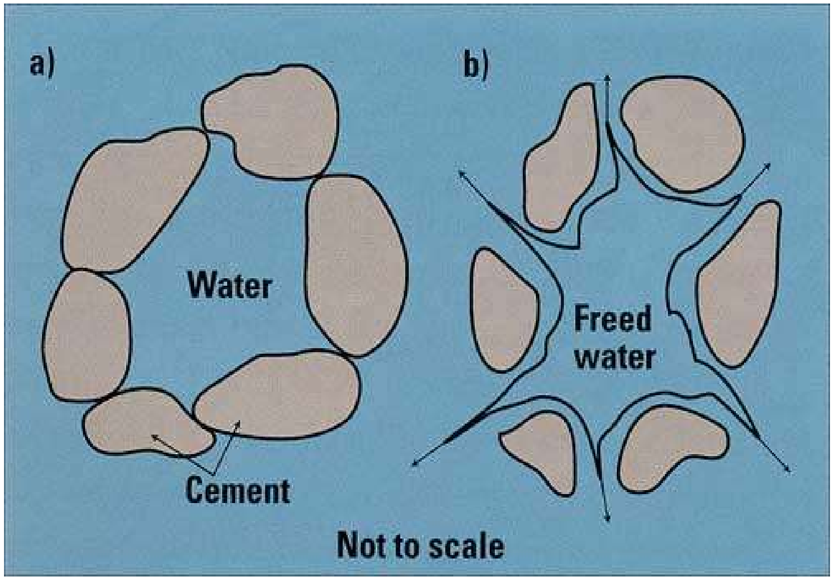
Retarding admixtures are used to delay the setting or hardening rate of concrete. They will not decrease the initial concrete temperature. They are typically used during hot weather to:

- 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.



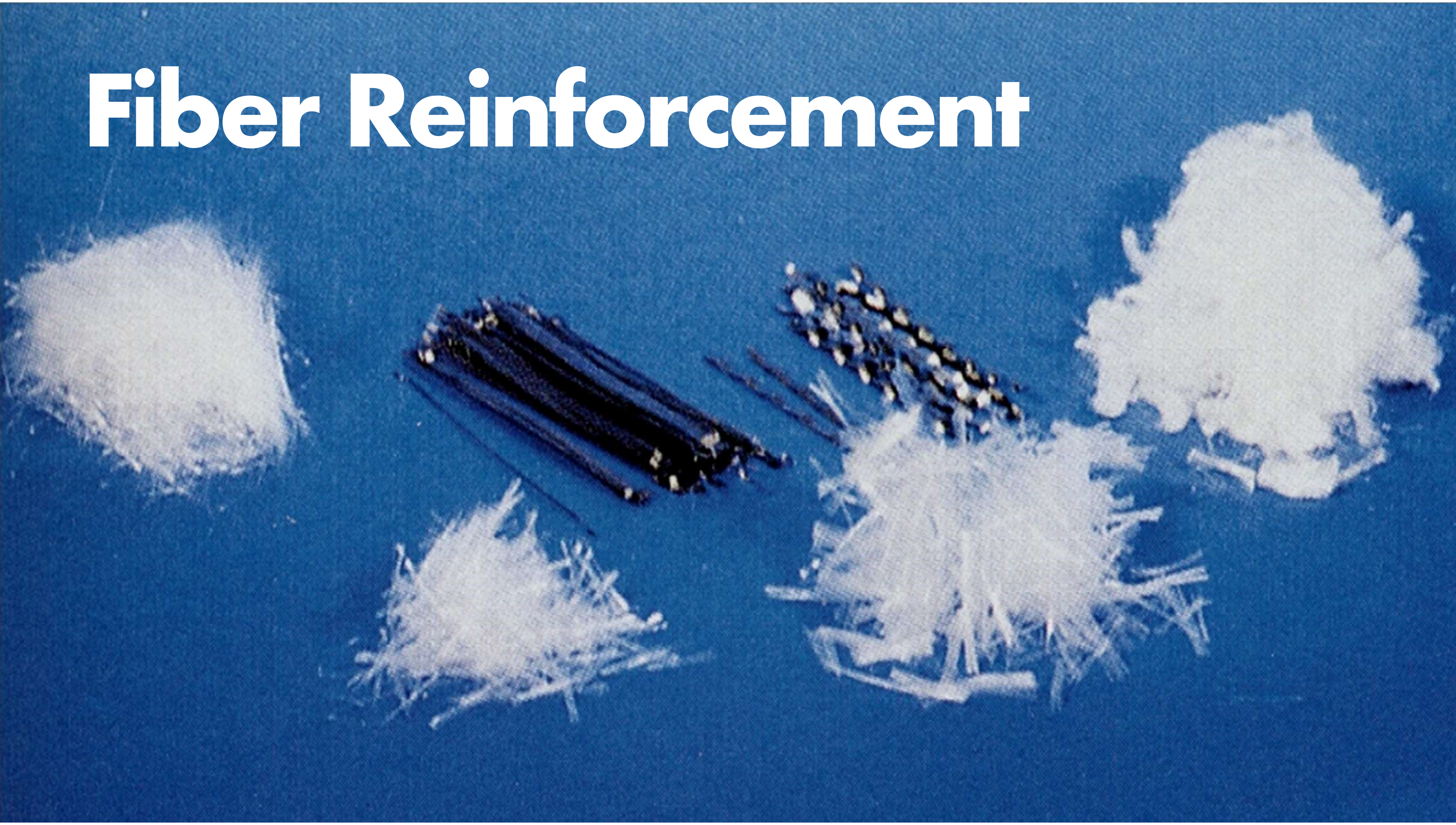
# Water Reducing Admixtures

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).

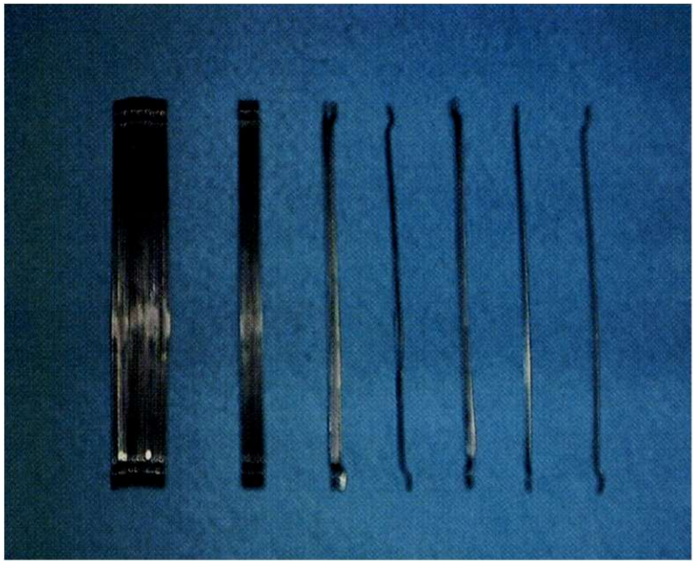
- available in a variety of shapes, sizes and thicknesses
- may be round, flat, crimped or deformed with lengths from ¼ inch to 6 inches
- added to concrete in low volume dosages (often less than 1%)
- provide secondary reinforcement
- depending on fiber type can improve impact resistance, abrasion resistance, 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 (typical) to 5.0lb/yd$^3$
- useful in reducing early age shrinkage and subsidence cracking
- common in concrete overlays
- most synthetic fibers are touted as 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/yd$^3$
- 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!

# Thank You!

- Video and handouts of today's webinar
- Webinar schedule & registration
- MCA Annual Membership Meeting – Feb. 17, 9:30 am
- Sponsorships still available

https://www.miconcrete.org/annual-conference

SUPERIOR MATERIALS

SOLUTIONS FOR YOUR ENVIRONMENT®

ST MARYS

MICHIGAN CONCRETE ASSOCIATION