March 2020

concrete solutions®

CONCRETE MATRIX

The CONCRETE MATRIX is presented as a guide to a better understanding of concrete properties. It is not intended as a blueprint for the formulation of individual concrete mixes. While many aspects of concrete are considered, this representation is not intended to illustrate all potential concrete properties.

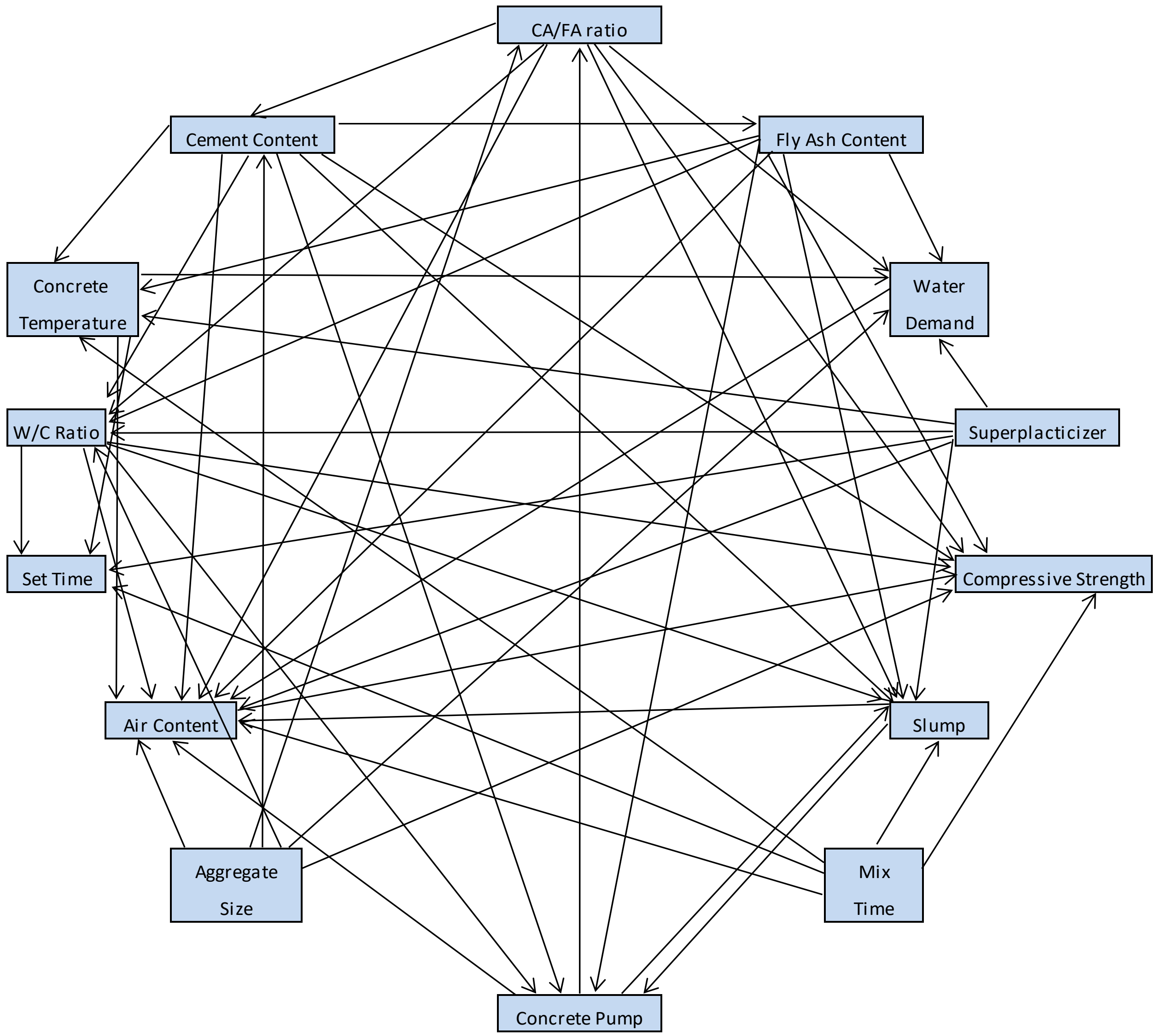
At one time or another, many of us have been involved in a home do-it-yourself project that required the use of ready mix concrete. Perhaps we obtained some sand, gravel and a sack of cement and combined these materials in a small mixer or even just a wheelbarrow. Or we may have purchased the sand, gravel and cement pre-mixed in a bag and we just added water. Certainly concrete production can be as simple as this with the finished product results quite adequate for the intended job.

But in today's commercial concrete market, there is an ever present effort to push the limits of all aspects of the finished properties of concrete, including compressive strength, flexible strength, durability, architectural appearance and economy. To accomplish this, a wide variety of high quality chemical and mineral admixtures are utilized. These are coupled with variations in concrete mix design and project specification criteria and a variety of placing methods. The result is a complex matrix of inter-related properties. In some cases, many of the desired properties of the finished product can be accomplished at the same time. In other cases, specific properties of the finished concrete become mutually exclusive of other properties. The old saying that "you can't have your cake and eat it too" is definitely applicable in these cases. An adjustment in any one property will have a primary effect on the performance of the mix design as well as side effects which must be considered, but oftentimes are not, with negative results. As an example, an increase in cement content might be

called for with the intended result of higher earlier strength. Secondary side effects of this adjustment would be: 1. an increase in the temperature of the mix which will produce shorter set times, 2. a decrease in the air content of air entrained mixes, 3. a possible reduction in slump and thus workability.

To help you understand the interrelatedness of a variety of the most common concrete mix design properties, chemical and mineral admixtures, and placing methods, CalPortland has developed a CONCRETE MATRIX which illustrates these properties in a cause and effect relationship.

CALPORTLAND - CONCRETE MATRIX



CONCRETE TEMPERATURE IMPACTS:

- Water Demand: The amount of water required in a concrete mix to produce a given slump will be higher in concrete mixes with higher temperatures. This can be a seasonal situation where concrete temperatures are usually higher in the summertime.
- Air Content: With a fixed amount of air entraining agent, less entrained air will be formed in concrete that has higher temperatures. The amount of air entraining agent needed to produce a fixed amount of air must be increased for mixes that will produce higher internal temperatures.

AIR CONTENT IMPACTS:

- Water Demand: In some instances, an increase in entrained air will allow for a reduction in the amount of water required to produce a given slump. This is especially true in mixes with lower cement contents (470 pounds and less). However, air entraining agents should not be thought of as plasticizers.
- Compressive Strength: An increase in the entrained air content will produce a decrease in the compressive strength for concrete mixes with generally higher cement contents. A general rule of thumb would be to figure a 5% reduction in compressive strength at 28 days for every 1% increase in entrained air content.

AGGREGATE SIZE IMPACTS:

- Water/Cement Ratio: Concrete mixes designed with larger top sized aggregates (1" and 1-1/2") will require less water to produce a concrete mix of a given slump than mixes designed with smaller sixed aggregates (3/8" and sand). The void content (the space between all aggregate particles) is higher in mixes with smaller aggregates thus necessitating additional water for workability which results in higher water/cement ratios.
- Cement Content: Because the water content is increased for mixes designed with smaller sized aggregates, the amount of cement will also increase if a fixed water/cement ratio is desired.
- Course Aggregate/Fine Aggregate Ratio (CA/FA Ratio): Because mixes designed with larger top sized aggregates have fewer void spaces between the aggregate particles, less fine aggregate (sand) is usually required to fill these voids thus allowing a change in the CA/FA Ratio.
- Water Demand: Again, less void space between the aggregate particles in mixes designed with larger top sized aggregates will require less water to produce a given slump.
- Compressive Strength: The strength of a specified coarse concrete aggregate is fixed and is based in large part to the material and the geological formation. The cement paste that surrounds this aggregate, however, can be created with cement, fly ash, sand, water and a variety of chemical and mineral admixtures. The quality (strength) of the paste can vary tremendously and can actually be designed to be stronger than the aggregate itself.

CONCRETE PUMP IMPACTS:

- Air Content: Entrained air contents as measured at the discharge chute of a ready mix truck will be altered after being put through a concrete pump. The change will be based on the type of pump and configuration of the boom and hose. Sometimes the air content is increased and sometimes it is decreased.
- Slump: Concrete slump is generally (but not always) reduced after going through a concrete pump. This is especially true if the aggregates are not completely saturated with water at the time of batching

SLUMP IMPACTS:

- Air Content: Low slump concrete will require a higher dosage of air entraining agent to produce a given entrained air content than moderate or high slump concrete.
- Concrete Pump: Generally, lower slump concrete is more difficult to pump than higher slump concrete.

(Please note that slump does not affect compressive strength. Compressive strength is primarily affected by the water/cement ratio and air content.)

SUPERPLASTICIZER IMPACTS:

- Air Content: Superplasticizers tend to decrease or even eliminate entrained air. To obtain proper percentages of entrained air, dosages of air entraining agents may have to be abnormally increased and monitored.
- Set Time: Set times can vary widely from load to load. Some loads will be retarded and other loads will not be affected at all resulting in erratic set times. (The use of mid-range plasticizers will eliminate this variation in set times.)
- Water/Cement Ratio: The use of superplasticizers in a concrete mix will reduce the amount of water required thus lowering the water/cement ratio while still producing a mix of a given slump.
- Concrete Temperature: As a general rule, superplasticizers will help suppress concrete temperature gain during the period that they are active (generally 30 to 45 minutes).
- Water Demand: For a given slump the water demand will be lowered significantly.

COARSE AGGREGATE / FINE AGGREGATE RATIO IMPACTS:

- Cement Content: Over-sanded mixes will require additional cement to maintain a given compressive strength.
- Water/Cement Ratio: Over-sanded mixes will require additional water to maintain a given slump.
- Air Content: With the same amount of air entraining agent, rocky mixes will produce concrete with higher entrained air contents.
- Concrete Pump: Rocky mixes may prove to be more difficult to place with a concrete pump. In some cases, material segregation can occur within the pump line creating plugs and lost time. Conversely, over-sanded mixes without an increase cement content can result in mixes with too little lubrication to pump efficiently.
- Slump: Rockier mixes will have a higher slump with a fixed amount of water. Sandy mixes will have less slump with this same amount of water.
- Compressive Strength: With a fixed amount of cement and water in the design, rockier mixes will produce higher compressive strengths and sandy mixes will produce lower compressive strengths.

MIX TIME IMPACTS:

- Air Content: The entrained air content of a concrete mix will be reduced as the mix time is extended.
- Concrete Temperature: As concrete is allowed to mix for longer periods of time, the temperature will increase. This is a natural result of the cement and water reacting together and the internal friction of the mix.
- Slump: Longer mix times will produce lower slumps.
- Compressive Strength: Studies have shown that concrete mixed for prolonged periods of time will have lower compressive strengths.

FLY ASH CONTENT IMPACTS:

- Concrete Temperature: If a percentage of the cement content is being replaced with fly ash, the reduced cement content will produce less total heat thus lowering the concrete temperature.
- Water/Cement Ratio: Fly ash particles are round and impart a “ball bearing” quality (increased workability) to the concrete mix. This can allow the mix to be designed with less “water of convenience” and a lower water/cement ratio.
- Air Content: Type “F” ashes contain a certain amount of carbon. There are certain air entraining admixtures that are made with products that have an attraction to this carbon. The net result can be that the air entraining admix is not uniformly distributed throughout the concrete mix and the desired air content is not achieved.
- Concrete Pump: Concrete mixes made with fly ash are often easier to pump.
- Slump: Because fly ash particles are round and impart a “ball bearing” quality to the cement paste, slumps are often times increased with no addition of water.
- Compressive Strength: Fly ash chemically reacts with by-products from the cement/water reaction. Often, the early compressive strengths are reduced in mixes where a percentage of the cement has been replaced with fly ash. However, the fly ash acts as an effective secondary cement and can improve compressive strengths at 56, 90, 180 and 360 days.

CEMENT CONTENT IMPACTS:

- Fly Ash Content: Fly ash is usually added to a concrete mix design as a percentage of the cement. To fully react with by-products from the cement/water reaction fly ash is usually specified to be between 15% and 25% of the cement content.
- Water Demand: To produce a concrete mix with a given consistency, an increase in the cement content may necessitate an increase in the water content.
- Compressive Strength: An increase in the cement content will produce an increase in the compressive strength with a fixed amount of water. There are levels where the effects of diminishing returns are encountered and ultimate strengths are achieved.
- Slump: Higher cement contents produce concrete mixes that are stiffer and stickier thus affecting the mix consistency, or slump.
- Concrete Pump: Concrete mixes with low cement contents are more difficult to pump than mixes with higher cement contents.
- Air Content: Higher cement contents will result in lower entrained air contents if a fixed amount of air entraining admixture is used.
- Concrete Temperature: A by-product of the chemical reaction between cement and water is heat. Increased amounts of cement produce increased concrete temperatures.
- Water/Cement Ratio: Increases in cement content will produce lower water/cement ratios if the water content is held steady.

WATER/CEMENT RATIO IMPACTS:

- Compressive Strength: It is a standard rule that lower water/cement ratios (weight of water in pounds divided by the weight of cement in pounds) produce higher compressive strengths. Unfortunately, the amount of water cannot be reduced to the minimum required for complete cement hydration. Additional water (water of convenience) is required for workability and finishing properties.
- Slump: Lower water/cement ratios produce concrete mixes with lower slumps and visa versa. Oftentimes, the advantages of the lower water/cement ratios can be gained and the workability of the concrete mix can be improved with the addition of plasticizers (normal, mid-range or superplasticizers).
- Air Content: It is usually very difficult to produce an efficient entrained air void system in concrete mixes with very low water/cement ratios (i.e. low slump concrete). Increased doses of air entraining agent are often required coupled with additional monitoring and testing.

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