HIGH STRENGTH CONCRETE

DISCUSSION:

High strength concrete is generally defined as concrete that has a specified average compressive strength of 6,000 psi or more. Proportioning of mixtures becomes much more critical with high strength concrete.
To successfully proportion high strength mixtures carefully selected cement, mineral admixtures, chemical admixtures, aggregates, and low water-to-cementitious ratios are employed. The purpose of this document is provide specific industry guidelines for the selection and proportioning of high strength concrete mixtures. For more details about high strength concrete, ACI 211.4R-93 "Guide for Selecting Proportions for High Strength Concrete with Portland Cement and Flyash" is recommended.

REQUIRED STRENGTH:

High strength concrete mix designs can be proportioned based on laboratory trial batch method or field experience as per ACI 318. When the field experience method is incorporated it is recommended, by ACI 211.4R-93, that the producer use the *larger value calculation* of the two equations listed below to determine the required average strength (f_{cr}'):

$$f_{cr}' = f_c' + 1.34s$$
$$f_{cr}' = 0.90f_c' + 2.33s$$

When the laboratory trial batch method is incorporated it is recommended by ACI 211.4R-93 that the producer use the equation listed below to determine the required average strength (f_{cr}'):

$$f_{cr}' = \frac{(f_c' + 1400)}{0.90}$$

Compressive strength may not be the only consideration when selecting ingredients and designing a high strength mixture. Other considerations may be modulus of elasticity, flexural or tensile strength, heat of hydration, drying shrinkage, creep, durability, permeability, rate of set, or workability.

INGREDIENT SELECTION:

Portland cement:
One of the most important steps in the ingredient selection process is the type and source of cement. There are more variations in the chemical composition and physical properties of cement sources than any other material used. Producers must determine through acceptance testing both the best performing cement and the optimum cement content. For any given mix design there is an optimum cement content where increasing the cement produces little or no improvement in strength.

Flyash:
Flyash is *highly* recommended in high strength concrete to achieve fuller hydration rates and higher ultimate strengths. These products help control temperature rise, lower water demand, and improve workability. However, high early strengths may be decreased. An ideal flyash would meet the requirements of ASTM C 618 Class C or F, have a maximum loss on ignition of 3.0%, and a high fineness gradation. Listed below are the recommended flyash replacements of cement:

Flyash	Recommended replacement (percent by weight)
Class F	15 to 25
Class C	20 to 35
Source: ACI 211.4R-93	

Silica Fume:
Silica fumes, such as **RUSSTECH CSF** have been considered for production of high strength concrete and significantly reduce the permeability of the concrete and increases the early and ultimate compressive strength. **RUSSTECH CSF** is recommended for use at a rate of 5 to 15% by weight of the cement.

Coarse Aggregate:
High strength concrete usually incorporates normal weight aggregate and special attention should be taken when proportioning and choosing the coarse aggregate. The aggregate needs to be free of surface coatings such as dust, be sufficiently hard, free of fissures, and have an optimized gradation. Sometimes it may be necessary to blend two coarse aggregates to adequately optimize the gradation. Smaller top size aggregates have been documented to produce higher strengths. Listed below are the suggested maximum top size coarse aggregate:

Suggested Maximum Top Size Coarse Aggregate	
Required concrete strength, psi	Suggested maximum top size coarse aggregate, in.
< 9,000	3/4 to 1
> 9,000	3/8 to 1/2
Source: ACI 211.4R-93	

The optimum coarse aggregate content will be higher than normal concrete due to the high cementitious content. Listed below are the recommended volume of coarse aggregate per unit volume of concrete:

Optimum coarse aggregate contents for nominal maximum sizes of aggregates to be used with sand with a fineness modulus of 2.5 to 3.2				
Nominal maximum size, in.	3/8	½	3/4	1
Volume of oven-dry rodded coarse aggregate	0.65	0.68	0.72	0.75
Source: ACI 211.4R-93				

Fine Aggregate:
The shape of the particles and the gradation of the sand are important in the design of high strength concrete. The fine aggregate volume should be reduced to the minimum necessary to produce adequate workability, since the volume of fines from cementitious is so high. Fineness modulus between 2.5 and 3.2 are desirable for high strength mixtures. If fineness modulus is less than 2.5, the concrete may be have a higher water demand and finishability may be sticky.

Chemical Admixtures:
In high strength concrete production, chemical admixtures are essential to reduce water requirement (by up to 40%) rather than increase total cementitious and to achieve workable slumps.

The use of admixtures will:

- Improve and control rate of set
- Control slump loss
- Accelerate strength gain
- Improve durability and workability

Generally, high strength mixes contain both high-range water reducers (super plasticizers) such as: **SUPERFLO 443**, **SUPERFLO 2000RM**, or **SUPERFLO 2000SCC** *and* a retarding water-reducer such as **LC-500**, **LC-400P, or LC-400R**. High strength concretes are usually intentionally retarded to help facilitate fuller hydration rates and higher ultimate strengths.

These mix designs tend to be "sticky" due to the low water contents and high cementitious factors. Stickiness in these mixes can be reduced by incorporating a mid-range water reducer, such as **FINISHEASE NC,** in addition to the high-range water reducer (high- range water reducer dose can usually be reduced).

The admixture performance is influenced by the particular set of cementitious ingredients. Trial mixes with varying amounts of admixture need to be run to determine the optimum dosage and combination of admixtures that best meets mix requirements.

W/CEMENTITIOUS RATIO:

The water-cementitious ratio is the single most important variable in the production of high strength concrete. Water content in the high-range water reducer and the mid-range water reducer should be considered part of the w/c + p ratio. Listed below are the recommended maximum water-cementitious ratios for *non-air entrained* high strength concrete:

Field Strength fcr', psi		w/c + p			
		Maximum-size Coarse aggregate, in.			
		3/8	1/2	3/4	1
7000	28-day	0.50	0.48	0.45	0.43
	56-day	0.55	0.52	0.48	0.46
8000	28-day	0.44	0.42	0.40	0.38
	56-day	0.48	0.45	0.42	0.40
9000	28-day	0.38	0.36	0.35	0.34
	56-day	0.42	0.39	0.37	0.36
10,000	28-day	0.33	0.32	0.31	0.30
	56-day	0.37	0.35	0.33	0.32
11,000	28-day	0.30	0.29	0.27	0.27
	56-day	0.33	0.31	0.29	0.29
12,000	28-day	0.27	0.26	0.25	0.25
	56-day	0.30	0.28	0.27	0.26
Source: ACI 211.4R-93					

SLUMP:

High strength concrete mixes, generally, are difficult to place due to the higher percentage of coarse aggregate, low water-cementitious ratio, and higher amounts of cementitious materials. Consequently, placements need to be at higher slumps. The mix should be designed for slumps in excess of 8 inches to control slump loss and fill voids between closely spaced reinforcement.

In situations where slump loss becomes a problem, a placeable slump can be restored by re-dosing (once) the high-range water reducer in the concrete. A second dose of superplasticizer, also, will increase compressive strengths at all ages and is very effective in hot weather concreting applications.

TEST METHODS:

Standard ASTM or AASHTO test methods should be followed when testing high strength concrete. It is important to note that potential strength for a particular set of materials can be determined only if test cylinders are made and tested under standard conditions. A set of at least 2 test specimens should made for each age and test situation.

Usually, 6 x12 test molds are the standard strength evaluation of high performance concrete. In some cases 4 x 8 test molds have been used for strength measurement. Strength measurements of 4 x 8 test molds are not interchangeable with strength measurements produced from 6 x 12 test molds.

The type of test cylinder mold incorporated will have a significant effect on compressive strength results. Steel test cylinder molds produce more consistent test results than plastic test cylinder molds. Cardboard molds are *not* recommended when testing high strength concrete. Plastic test cylinder molds have been used successfully on many high strength concrete projects. The same type of test cylinder molds should be used on the jobsite acceptance testing as were used on the trial mixes.

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