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Concrete mix design with fly ash and superplasticizer

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Abstract

All precast concrete producers can now use a group of materials called "fly ash" to improve the quality and durability of their products. Fly ash improves concrete's workability, pumpability, cohesiveness, finish, ultimate strength, and durability as well as solved many problems experienced with concrete today—and all for less cost. Fly ash, however, must be used with care. Without adequate knowledge of its use and taking proper precautions, problems can result in mixing, setting time, strength development, and durability.

Keywords: Reinforced, Fly ash, Superplasticizer, Compressive strength

1. Introduction:

Concrete: is a composite material composed of water, coarse granular material embedded in a hard matrix of material that fills the space between the aggregate particles and glues them together. Famous concrete structures include the Hoover Dam, the Panama Canal and the Roman Pantheon. The earliest large-scale users of concrete technology were the ancient Romans, and concrete was widely used in the Roman Empire. The Colosseum in Rome was built largely of concrete, and the concrete dome of the Pantheon is the world's largest unreinforced concrete dome. After the Roman Empire collapsed, use of concrete became rare until the technology was re-pioneered in the mid-18th century. Today, concrete is the most widely used man-made material.

2. Usage of Concrete

Highways, runways, parking structures, dams, gates, fences and poles and even boats. Concrete is used in large quantities almost everywhere mankind has a need for infrastructure. The amount of concrete used worldwide, ton for ton, is twice that of steel, wood, plastics, and aluminum combined. Concrete's use in the modern world is exceeded only by that of naturally occurring water. Concrete is also the basis of a large commercial industry. Globally, the ready-mix concrete industry, the largest segment of the concrete market, is projected to exceed \$100 billion in revenue by 2015. In the United States alone, concrete production is a \$30-billion-per-year industry, considering only the value of the ready-mixed concrete sold each year. Given the size of the concrete industry, and the fundamental way concrete is used to shape the infrastructure of the modern world, it is difficult to overstate the role this material plays today.

3. Composition of Concrete:

There are many types of concrete available, created by varying the proportions of the main ingredients below. In this way, or by substitution for the cementitious and aggregate phases, the finished product can be tailored to its application with varying strength, density, or chemical and thermal resistance properties.

"Aggregate" consists of large chunks of material in a concrete mix, generally a coarse gravel or crushed rock such as limestone, or granite, along with finer materials such as sand.

"Cement", commonly Portland cement, and other cementitious materials such as fly ash and slag cement, serve as a binder for the aggregate.

Water is then mixed with this dry compost, which produces a semi-liquid that workers can shape (typically by pouring it into a form). The concrete solidifies and hardens to rock-hard strength through a chemical process called hydration. The water reacts with the cement, which bonds the other components together, creating a robust stone-like material. "Chemical admixtures" are added to achieve varied properties.

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These ingredients may speed or slow down the rate at which the concrete hardens, and impart many other useful properties including increased tensile strength and water resistance. "Reinforcements" are often added to concrete. Concrete can be formulated with high compressive strength, but always has lower tensile strength. For this reason it is usually reinforced with materials that are strong in tension (often steel) or, with the advent of modern technology, cross-linking styrene acrylic polymers. "Mineral admixtures" are becoming more popular in recent decades. The use of recycled materials as concrete ingredients has been gaining popularity because of increasingly stringent environmental legislation, and the discovery that such materials often have complementary and valuable properties. The most conspicuous of these are fly ash, a by-product of coal-fired power plants, and silica fume, a byproduct of industrial electric arc furnaces. The use of these materials in concrete reduces the amount of resources required, as the ash and fume act as a cement replacement. This displaces some cement production, an energetically expensive and environmentally problematic process, while reducing the amount of industrial waste that must be disposed of. The mix design depends on the type of structure being built, how the concrete is mixed and delivered, and how it is placed to form the structure.

4. Mixing Concrete

Thorough mixing is essential for the production of uniform, high-quality concrete. For this reason equipment and methods should be capable of effectively mixing concrete materials containing the largest specified aggregate to produce uniform mixtures of the lowest slump practical for the work. Separate paste mixing has shown that the mixing of cement and water into a paste before combining these materials with aggregates can increase the compressive strength of the resulting concrete. The paste is generally mixed in a high-speed, shear-type mixer at a w/cm (water to cement ratio) of 0.30 to 0.45 by mass. The cement paste premix may include admixtures such as accelerators or retarders, Superplasticizers, pigments, or silica fume. The premixed paste is then blended with aggregates and any remaining batch water and final mixing is completed with conventional concrete mixing equipment.

High-energy mixed (HEM) concrete is produced by means of high-speed mixing of cement, water and sand with net specific energy consumption of at least 5 kilojoules per kilogram of the mix. A plasticizer or a Superplasticizers is then added to the activated mixture, which can later be mixed with aggregates in a conventional concrete mixer. In this process, sand provides dissipation of energy and creates high-shear conditions on the surface of cement particles. This results in the full volume of water interacting with cement. The liquid activated mixture can be used by itself or foamed (expanded) for lightweight concrete. HEM concrete hardens in low and subzero temperature conditions and possesses an increased volume of gel, which drastically reduces capillarity in solid and porous materials.

5. Properties:

Concrete has relatively high compressive strength, but much lower tensile strength. For this reason it is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels, but starts decreasing at higher stress levels as matrix cracking develops. Concrete has a very low coefficient of thermal expansion and shrinks as it matures. All concrete structures crack to some extent, due to shrinkage and tension. Concrete

that is subjected to long-duration forces are prone to creep. Tests can be performed to ensure that the properties of concrete correspond to specifications for the application. Different mixes of concrete ingredients produce different strengths, which are measured in psi or MPa.

Different strengths of concrete are used for different purposes. Very low-strength (2000 psi or less) concrete may be used when the concrete must be lightweight. Lightweight concrete is often achieved by adding air, foams, or lightweight aggregates, with the side effect that the strength is reduced. For most routine uses, 3000-psi to 4000-psi concrete is often used. 5000-psi concrete is readily commercially available as a more durable, although more expensive, option. 5000-psi concrete is often used for larger civil projects. Strengths above 5000 psi are often used for specific building elements. For example, the lower floor columns of high-rise concrete buildings may use concrete of 12,000 psi or more, to keep the size of the columns small. Bridges may use long beams of 10,000 psi concrete to lower the number of spans required. Occasionally, other structural needs may require high-strength concrete. If a structure must be very rigid, concrete of very high strength may be specified, even much stronger than is required to bear the service loads. Strengths as high as 19,000 psi have been used commercially for these reasons.



Compression testing of a concrete cylinder

Imperial Strength	Metric Equivalent
2000 psi	14 MPa
2500 psi	18 MPa
3000 psi	20 MPa
3500 psi	25 MPa
4000 psi	30 MPa
5000 psi	35 MPa
6000 psi	40 MPa
7000 psi	50 MPa
8000 psi	55 MPa
10,000 psi	70 MPa
12,000 psi	80 MPa
19,000 psi	130 MPa
36,000 psi	250 MPa

6. What Is Fly Ash?

Fly ash is a group of materials that can vary significantly in composition. It is the residue left from burning coal. It mixes with flue gases that result when powdered coal is used to produce electric power. Since the oil crisis of the 1970s, the use of coal has increased. In 1992, 460 million metric tons of coal ash were produced worldwide. About 10 percent of this

was produced as fly ash in the United States. Economically, it makes sense to use as much of this low-cost ash as possible, especially if it can be used in concrete as a substitute for cement. Coal is the product of millions of years of decomposing vegetable matter under pressure. In addition, electric companies optimize power production from coal using additives such as flue-gas conditioners, sodium sulfate, oil, and other additives to control corrosion, emissions, and fouling. The resulting fly ash can have a variable composition and contain several additives as well as products from incomplete combustion. Most fly ash is pozzolanic, which means it's a siliceous or siliceous-and-aluminous material that reacts with calcium hydroxide to form a cement. When Portland cement reacts with water, it produces a hydrated calcium silicate (CSH) and lime. The hydrated silicate develops strength and the lime fills the voids. Properly selected fly ash reacts with the lime to form CSH—the same cementing product as in Portland cement. This reaction of fly ash with lime in concrete improves strength. Typically, fly ash is added to structural concrete at 15-35 percent by weight of the cement, but up to 70 percent is added for mass concrete used in dams, roller-compacted concrete pavements, and parking areas. Special care must be taken in selecting fly ash to ensure improved properties in concrete.

7. Standards

There are two classes of fly ash: "F" is made from burning anthracite and/or bituminous coal, and "C" is produced from lignite or subbituminous coal. The chemical part of the specification requires only a combined total of silica, alumina, and iron oxide. It does not specify the amount of silica that reacts with lime to produce added strength. The alumina content could be high in fly ash, which could be detrimental because more sulfate to control its reactivity might be required. Sulfate is added to the cement to control only the setting reactions of the aluminates and ferrites in the cement. However, the amount is limited because expansive reactions are possible after the concrete has set. This amount of sulfate does not take into account the extra aluminates that can be added when fly ash is used. Too much iron oxide will retard the setting time. Both class C fly ash and slag have about 35 percent silica and much lower calcium oxide than Portland cement. In most cases, lower calcium oxide means better durability. In some fly ash, alumina and iron oxide can be quite high, leading to lower strength and unusual setting time problems. The carbon content was reported in some to be so high that it was beyond the special footnoted exception in ASTM C618.

8. Advantages

The advantages of using fly ash far outweigh the disadvantages. The most important benefit is reduced permeability to water and aggressive chemicals. Properly cured concrete made with fly ash creates a denser product because the size of the pores are reduced. This increases strength and reduces permeability. Today, there are at least two ways to make fly ash more beneficial: a dry process that involves triboelectric static separation and a wet process based on froth flotation. These procedures generally lower the carbon content and the LOI of fly ash. The cost of an additional storage bin should be easily covered by the reduction in the cost of the concrete and the added benefits to the concrete. Low-carbon fly ash or the use of a better air-entraining agent at a higher-than-usual addition rate can control the problem of freeze-thaw durability.

9. The advantages of fly ash concrete over the corresponding plain cement concrete are:

- Improved workability.
- Lower heat of hydration.
- The increase in creep with fly ash content upto 15% is negligible.
- Increases the modulus of elasticity of concrete when concretes of the same strength with and without fly ash are compared.
- Superior resistance to freezing and thawing.
- Improved sulphate resistance.
- Lower water and air permeability.
- Lower leaching of lime liberated during hydrated of cement.
- Reduced alkali-aggregate reactions.
- Greater resistance to attack of aggressive waters

Since a huge quantity of cement is used in concrete in mass concrete construction and the cost of fly ash is negligible as compared to that of the cement, the use of fly ash concrete brings about a substantial saving in cement consumption and overall construction cost. Fly ash concrete may be used in general RCC structures including high strength concrete without any risk of steel corrosion. Researchers have proved that concrete with approved quality fly ash does not induces corrosion of reinforcing steel even in marine and industrial aggressive environments. With proper mix design the 7 and 28-days strength of fly ash concrete may be equal or even more than plain concrete. The 90 days strength of fly ash concrete may be more than 140% of plain concrete. The cost of fly ash is negligible. Therefore the use of fly ash in structural concrete may bring a substantial saving in cement consumption and overall cost of concrete production. The fly ash is an industrial waste and great hazard for our environment. The designers of concrete structures therefore must incorporate the use of fly ash in their structural concrete.

10. Example of Mix Design

A mix is to be designed for characteristic strength of 50 N/mm² at 28 days having target strength of 62 N/mm² at 28 days. 30% of fly ash is to be included by weight of cementitious material. Maximum w/c ratio or w/c + f.a. ratio = 0.4, minimum cement concrete or cement + f.a. content = 400 kg/m³. Slump 50±10 mm.

11. Date of Material

Cement: OPC, 53 grade, specific gravity = 3.15

Fine aggregate: From river of Zone II Sp.gr. = 2.6

Coarse aggregate: Crushed 20 mm graded, Sp. Gr. = 2.6

Fly ash: As per I.S.: 3812, Sp. Gr = 2.25

Superplasticizer: Liquid Sp.gr. 1.15, dosage 1% b.w.c. for required

12. Workability

Water content reduction for fly ash concrete: 5%

Increase in cementitious material: 12%

Designed plain concrete of above strength and workability:

Water (free) = 170 kg/m³

OP Cement = 430 kg/m³

Fine aggregate = 707 kg/m³

Coarse aggregate = 1060 kg/m³

Superplasticizer = 4.300 kg/m³ = 3739 ml/m³

Total = Sum of all of the above = 2371 kg/m³ (air = 1%)

Fly ash concrete of above strength and workability:

Total cementitious	wt. (kg/m ³)	vol (m ³)
Material = 1.12 x 430 = 482		
OP Cement = 482 x 0.70 = 337	337 / 3150	= 0.1070
Fly ash= 482 x 0.30 = 145	145 / 2250	= 0.0644
Water (free) = 170 x 0.95 = 162	162 / 1000	= 0.1620
Superplasticizer= 482 x 0.01 = 4.82*	4.82 / 1150	= 0.0042
Air = 1%		= 0.0100
Total		= 0.3476
Aggregates =		
	1-0.3476	= 0.6524
Coarse aggregate(SSD) unaltered =1060	1060 / 2600	= 0.4077
Fine aggregate = 0.2447x2600= 636	0.6524- 0.4077	= 0.2447
Total	= 2345	= 1

• Total dosages of superplasticizer may be reduced on actual trials. Standard deviation for fly ash concrete is assumed unaffected with the ash.

Comparison (kg/m³)

Materials	Plain Concrete	Fly ash Concrete
Water (free)	170	162
OP Cement	430	337
Fly ash	—	145
Fine aggregate	707	636
Coarse aggregate	1060	1060
Superplasticizer	4.300	4.820
	2371	2345

Saving in cement 430-337 = 93 kg/m³

It may be noticed that, for the fly ash concrete the total cementitious material is greater but the OP cement content is smaller, the fine aggregate content is reduced but the coarse aggregate content is deliberately the same, the water is reduced and the density is reduced because of the lower density of fly ash compared with cement.

Note that it should not be assumed that ggbfs concrete or other fly ash concretes would require the same adjustment. The factors can differ appreciably between materials, source and quantities and will be influenced by the proportion of ggbfs or fly ash, the cement content and other factors. The method, however will be applicable and can be used for any situation, provided the factors are known.

13. Method of Fly Ash Concrete mixing

For obtaining the best result the fly ash concrete should be prepared by the following mixing method:

About 3/4th quantity of the mixing water be taken in the concrete mixer. Weighted amount of the required quantity of fly ash then added to it and mixed for 30 sec. To the slurry of fly ash so obtained, weighted quantities of coarse aggregate, fine aggregate, cement and remaining quantity of the mixing water be added and mixed for 90 sec. However, if this is not convenient normal mixing method may be adopted i.e.

Weighted quantities of coarse aggregate, fine aggregate cement and fly ash should be put together in the concrete mixer and mixed dry for 30 sec. The required quantity of the mixing water then added and the mixing continued for 90 sec. The superplasticizer by added just before discharge of the mix from mixer.

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