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LECTURE NOTES

(MODULE-3)

MIX DESIGN

VI-SEMESTER

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Syllabus: ADMIXTURES: Classification, effect on fresh and hardened concrete, retention time, Dosage ant their effects, Influence on properties of paste, mortar, and concrete Types of concrete (in brief). MIX DESIGN PROCEDURE: Concept of Concrete Mix design, variables in proportioning, exposure conditions, Procedure of mix design as per IS 10262-2019, Numerical examples of Mix Design. Highlights of Other methods of Mix Design as per other codes.

ADMIXTURES

An admixture is defined as a material other than water, aggregate, used as an ingredient of concrete or mortar and added to the batch immediately before or during mixing.

Admixtures vary in composition from surfactants (a substance which tends to reduce the surface tension of a liquid in which it is dissolved) and soluble salts and polymers to insoluble minerals.

The reasons for the use of admixtures are outlined by the following functions that they perform:

1. Increase workability without increasing water content or decrease the water content at the same workability.
2. Retard or accelerate time of initial setting.
3. Reduce or prevent shrinkage or create slight expansion.
4. Modify the rate or capacity for bleeding.
5. Reduce segregation.
6. Improve pump ability.
7. Increase strength (compressive, tensile, or flexural).
8. Decrease permeability of concrete.
9. Improve impact and abrasion resistance.
10. Increase bond between existing and new concrete.

TYPES OF ADMIXTURES

1. **Chemical admixtures**

2. **Mineral admixtures**

1. CHEMICAL ADMIXTURES

Chemical admixtures are the ingredients in concrete other than Portland cement, water, and aggregate that is added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing and to overcome certain emergencies during concrete operations.

Successful use of admixtures depends on the use of appropriate methods of batching and concreting. Most admixtures are supplied in ready to use liquid form and are added to the concrete at the plant or at the jobsite. Certain admixtures (such as pigments, expansive agents, and pumping aids) are used only in extremely small amounts and are usually batched by hand from premeasured containers.

TYPES OF CHEMICAL ADMIXTURE

1. Plasticizers.
2. Super plasticizers.
3. Retarders and retarding plasticizers.
4. Accelerators and Accelerating Plasticizers.
5. Air-entraining Admixtures.

1. PLASTICIZERS

The organic substances or the combinations of organic and inorganic substances, which allow a high reduction in water content for the given workability or give a higher workability at the same water content, are termed as Plasticizing Admixtures.

These admixtures **lower the water required to attain a given slump, thus lowering the w/c ratio.** This will:

- improve the strength
- Improve the water tightness
- Improve durability.

Alternately it may be used to maintain the same w/c ratio but increase workability for difficult placement. Typical reductions in water requirements are 5-10%.

The water reducers reduce the electro negative charges on the fine cement particles allowing them to disperse more readily in the water. This reduces the tendency for flocculation of the cement particles in the paste.

The basic products constituting plasticizers are:

1. Anionic surfactants such as **lignosulphonates** and their modifications and derivatives, salts of sulphonates hydrocarbons.
2. Non-ionic surfactants such as **polyglycol esters,** acid of **hydroxylated carboxyl acids** and their modifications and derivatives.
3. Other products, such as **carbohydrates** etc.

Among these, calcium, sodium and ammonium lignosulphonates are the most used. Plasticizers are used in the amount of 0.1% to 0.4% by weight of cement. At these doses, at constant workability the reduction in mixing water is expected to be of the order of 5% to 15%. This naturally increases the strength. The increase in workability that can be expected, at the same w/c ratio, may be anything from 30 mm to 150 mm slump, depending on the dosage, initial slump of concrete, cement content and type.

ACTION OF PLASTICIZERS

The action of plasticizers is mainly to fluidify the mix and improve the workability of concrete, mortar or grout. The **mechanisms** that are involved could be explained in the following way:

Dispersion: Portland cement, being in fine state of division, will have a tendency of flocculate in wet concrete. These flocculation entraps certain amount of water used in the mix and thereby all the water is not freely available to fluidify the mix. When plasticizers are used, they get adsorbed on the cement particles. The adsorption of charged polymer on the particles of cement creates particle-to-particle repulsive forces which overcome the attractive forces. This repulsive force is called Zeta Potential, which depends on the base, solid content, quantity of plasticizer used. The overall result is that the cement particles are deflocculated and dispersed. When cement particles are deflocculated, the water trapped inside the flocs gets released and now available to fluidify the mix.

When cement particles get flocculated there will be inter-particles friction between particle to particle and floc to floc. But in the dispersed condition there is water in between the cement particle and hence the inter particle friction is reduced.

Retarding Effect: The plasticizer will get adsorbed on the surface of cement particles and form a thin sheath. This thin sheath inhibits the surface hydration reaction between water and cement as long as sufficient plasticizer molecules are available at the particle/solution interface. The quantity of available plasticizers will progressively decrease as the polymers become entrapped in hydration products.

SUPERPLASTICIZERS (HIGH RANGE WATER REDUCERS-HRWR)

Super plasticers constitute a relatively new category and improved version of plasticizer. They are chemically different from normal plasticizers. Use of super plasticizer permits the reduction of water to the extent up to 30 per cent without reducing workability in contrast to the possible reduction up to 15 per cent in case of plasticizers.

The use of super plasticizer is practiced for production of flowing, self-levelling, and self-compacting and the production of high strength and high performance concrete.

The mechanism of action of super plasticizers is more or less same in case of ordinary plasticizer. Only thing is that the super plasticizers are more powerful as dispersing agents and they are high range water reducers. They are called High Range Water Reducers in American literature. It is the use of super plasticizer which has made it possible to use w/c as low as 0.25 or even lower and yet to make flowing concrete to obtain strength of the order 120 MPa or more. It is the use of super plasticizer which has made it possible to use fly ash, slag and particularly silica fume to make high performance concrete.

Super plasticizers can produce:

- At the same w/c ratio much more workable concrete than the plain ones,
- For the same workability, it permits the use of lower w/c ratio,
- As a consequence of increased strength with lower w/c ratio, it also permits a reduction of cement content.

The super plasticizers also produce a homogeneous, cohesive concrete generally without any tendency for segregation and bleeding.

Classification of Super plasticizer:

Following are a few polymers which are commonly used as base for super plasticizers.

1. Sulphonated melamine-formaldehyde condensates (SMF)
2. Sulphonated naphthalene-formaldehyde condensates (SNF)
3. Modified lignosulphonates (MLS)

Advantages of HRWR

1. Significant water reduction;
2. Reduced cement contents;
3. Increased workability;
4. Reduced effort required for placement;
5. More effective use of cement;
6. More rapid rate of early strength development;
7. Increased long-term strength; and
8. Reduced permeability.

Disadvantages of HRWR:

1. Additional admixture cost (the concrete in-place cost may be reduced);
2. Slump loss greater than conventional concrete;
3. Modification of air-entraining admixture dosage;
4. Less responsive with some cement;
5. Mild discoloration of light-colored concrete; and
6. Air-void and color blemishes on exposed and formed Finishes.

EFFECTS OF SUPER PLASTICIZERS ON FRESH CONCRETE

It is to be noted that dramatic improvement in workability is not showing up when plasticizers or super plasticizers are added to very stiff or what is called zero slump concrete at nominal dosages. A mix with an initial slump of about 2 to 3 cm can only be fluidized by plasticizers or super plasticizers at nominal dosages. A high dosage is required to fluidify no slump concrete. An improvement in slump value can be obtained to the extent of 25 cm or more depending upon the initial slump of the mix, the dosage and cement content. It is often noticed that slump increases with increase in dosage. But there is no appreciable increase in slump beyond certain limit of dosage. As a matter of fact, the over dosage may sometime harm the concrete.

- Improved workability of fresh concrete (flowing concrete with use of super plasticizers **SP)**
- Some types may increase bleeding (hydroxycarboxylic acids).
- They tend to increase air entrainment (so less air entraining admixture can be used)
- Tend to retard set times.
- Rate of slump loss increases with normal-range water reducers about same for super plasticizers.

EFFECTS OF SUPER PLASTICIZERS ON HARDENED CONCRETE

- Increased compressive strength due to ability to reduce w/c ratio and better dispersion of cement in paste.

- Increased durability due to lower w/c ratio.
- SP Rapid strength gain without increased heat generation.
- SP used for high strength concrete.

Compatibility of super plasticizers and cement

It has been noticed that all super plasticizers are not showing the same extent of improvement in fluidity with all types of cements. Some super plasticizers may show higher fluidizing effect on some type of cement than other cement. There is nothing wrong with either the super plasticizer of that of cement. The fact is that they are just not compatible to show maximum fluidizing effect. Optimum fluidizing effect at lowest dosage is an economical consideration. Giving maximum fluidizing effect for a particular super plasticizer and cement is very complex involving many factors like composition of cement, fineness of cement etc.

Although compatibility problem looks to be very complex, it could be more or less solved by simple rough and ready field method. Incidentally this simple field test shows also the optimum dose of the super plasticizer to the cement.

Following methods could be adopted.

- Marsh cone test
- Mini slump test
- Flow table test.

Out of the above, Marsh cone test gives better results. In the Marsh cone test, cement slurry is made and its flow ability is found out. In concrete, really come to think of it, it is the cement paste that influence, it is the paste that influences flow ability.

Although, the quantity of aggregates, its shape and texture etc. will have some influence, it is the paste that will have greater influence. The presence of aggregate will make the test more complex and often erratic. Whereas grout alone will make the test simple, consistent and indicative of the fluidifying effect of super plasticizer with cement.

The following procedure is adopted in Marsh cone test.

Marsh cone is a conical brass vessel, which has a smooth aperture at the bottom of diameter 5 mm.

1. Take 2 kg cement, proposed to be used at the project. Take one liter of water (w/x = 0.5) and say 0.1% of plasticizer.
2. Mix them thoroughly in a mechanical mixer (Hobart mixer is preferable) for two minutes. Hand mixing does not give consistent results because of unavoidable lump formation which blocks the aperture. If hand mixing is done, the slurry should be sieved through 1.18mm sieves to exclude lumps.
3. Take one litre slurry and pour it into Marsh cone duly closing the aperture with a finger. Start a stop watch and simultaneously remove the finger. Find out the time taken in seconds, for complete flow out of the slurry. The time in seconds is called the "Marsh Cone Time".
4. Repeat the test with different dosages of plasticizer.
5. The dose at which the Marsh cone time is lowest is called the saturation point. The dose is the optimum dose for that brand of cement and plasticizer or super plasticizer for that w/c ratio.

RETARDERS

These are admixtures, which delay the setting time of concrete. (or)A retarder is an admixture that slows down the chemical process of hydration so that concrete remains plastic and workable for a longer time than concrete without the retarder.

Retarders are used to overcome the accelerating effect of high temperature on setting properties of concrete on hot weather concreting. The retarders are used in casting and consolidating large number of pours without the formation of cold joints. They are also used in grouting oil wells.

The retarders slow the rate of early hydration of C3S by extending the length of the dormant period. They also tend to retard the hydration of C3A phases. Delaying the introduction of the retarders until the concrete has been mixed (up to about 10 min) can enhance its performance. This is because some of the hydration reactions have already occurred and this allows the more of the retarder to react with the.C3S. Subsequent hydration may be more rapid, however, so strength development may not be slower than the unretarded mix. However overdosing may stop C3S hydration completely and the paste will never set.

The degree of effect of retarders can depend on the composition of the particular cement being used. It depends on the aluminate/sulfate ratio in the cement, and possibly the alkali oxides content.

Perhaps the most common known retarder is calcium sulphate. It is inter ground to retard the setting of cement. The appropriate amount of gypsum to be used must be determined carefully for the given job. Use of gypsum for the purpose of retarding setting time is only recommended when adequate inspection and control is available, otherwise, addition of excess amount may cause undesirable expansion and indefinite delay in the setting of concrete.

In addition to gypsum there are number of other materials found to be suitable for this purpose. They are: **starches, cellulose products, sugars, acids or salts of acids.** These chemicals may have variable action on different types of cement when used in different quantities.

Common **sugar is one of the** most effective retarding agents used as an admixture for delaying the setting time of concrete without detrimental effect on the ultimate strength.

Other admixtures which have been successfully used as retarding agents are Ligno**sulphonic acids and their salts, hydroxylated carboxylic acids and their salts** which in addition to the retarding effect also reduce the quantity of water requirement for a given workability. This also increases 28 days compressive strength by 10 to 20 percent. Materials like mucic acid, calcium acetate and commercial products by name "**Ray lig binder**" are used for set retarding purposes.

One of the instances where a retarding agent is used:

Sometimes concrete may have to be placed in difficult conditions and delay may occur in transporting and placing. In ready mixed concrete practices, concrete is manufactured in central batching plant and transported over a long distance to the job sites which may take considerable time. In the above cases the setting of concrete will have to be retarded, so that concrete when finally placed and compacted is in perfect plastic state.

Composition

1. Salts and derivatives of lingo sulfonates.
2. Salts and derivatives of hydroxyl carboxylic acids.
3. Sugars and their derivatives (a bag of sugar mixed in a truck of concrete can stop the set in case of emergency!).
4. Inorganic salts.

Effects on Concrete Properties

5. Delay the set of the concrete.
6. Because some are water reducers, they may increase the amount of entrained air.
7. Increase slump.
8. They may increase the rate of slump loss though the set has been retarded thus decreasing the time available for placing.

ACCELERATORS

Accelerating admixtures are added to concrete to increase the rate of early strength development in concrete to reduce the required period of curing.

- These are used to advance the time that a structure can be placed in service.
- These are used to increase the rate of strength gain of the concrete.
- They are used to speed construction permitting earlier removal of formwork, earlier finishing of surfaces, or earlier load carrying capacity.
- These also include admixtures for quick-setting applications, in a few minutes (like shot creting, plugging leaks and emergency repairs).
- They can also be beneficial for cold-weather concreting.

Composition

1. soluble inorganic salts (CaCI, carbonates, aluminates, fluorides, and ferric salts)
2. soluble organic compounds (triethanolamine, calcium formate, calcium acetate)

In the past one of the commonly used materials as an accelerator was **calcium chloride**. But, now days it is not used. Instead, some of the **soluble carbonates**, silicates **fluosilicates and** some of the organic compounds such as**triethenol amine** are used. Accelerators such as fluosilicates and triethenolamine are comparatively expensive.

Calcium chloride is the most popular choice due to low cost and high rate of acceleration for a given dosage. Sodium carbonate and sodium aluminates are the most common for **shotcreting.** The organic accelerators are most commonly used with water-reducers to offset the retarding affects.

Effect on Concrete Properties:

- They have the exact opposite effect of retarders; they increase the rate of hydration of C_3S by shortening the dormant period and also may increase the rate of hydration later on.
- Organic accelerators are believed to increase the rate of hydration of the C_3A.
- Quick-setting admixtures are believed to cause flash setting of C_3A.
- Expect little effect on air entrainment (though trial batches should be done)
- Less time for placing and handling will result.
- There may be a reduction in 28-day strength.
- Use of CaC1 reduces concrete resistance to sulfate attack and aggravates alkali aggregate reaction.
- Quick-setting admixtures will reduce durability.
- CaC1 may increase the rate of corrosion of reinforcing steel, though the levels of allowable CaC1 has not been agreed upon.
- Typically up to 2% CaC1 by wt of dry cement have been used in reinforced concrete if adequate cover of dense concrete in provided.
- General agreement that CaC1 should not be used in prestressed applications.

➢ AIR-ENTRAINING ADMIXTURE

Air entrained concrete is made by mixing a small quantity of air entraining agent or by using air entraining cement. These air entraining agents incorporate millions of no-coalescing air bubbles, which will act as flexible ball bearings and will modify the properties of plastic concrete regarding workability, segregation, bleeding and finishing quality of concrete. It also modifies the properties of hardened concrete regarding its resistance to frost action and permeability.

The air voids present in concrete can be brought under two groups:

(**a**) Entrained air (**b**) Entrapped air.

Entrained air is intentionally incorporated, minute spherical bubbles of size ranging from 5 microns to 80 microns distributed evenly in the entire mass of concrete. The entrapped air is the void present in the concrete due to insufficient compaction. These entrapped air voids may be of any shape and size normally embracing the contour of aggregate surfaces. Their size may range from 10 to 1000 microns or more and they are not uniformly distributed throughout the concrete mass.

Air Entraining Agents

The following types of air entraining agents are used for making air entrained concrete.

- Natural wood resins
- Animal and vegetable fats and oils, such as tallow, olive oil and their fatty acids such as stearic and oleic acids.
- Various wetting agents such as alkali salts or sulphated and sulphonated organic compounds.
- Water soluble soaps of resin acids, and animal and vegetable fatty acids.
- Miscellaneous materials such as the sodium salt of petroleum sulphonic acids.
- Hydrogen peroxide and aluminium powder, etc.

Factors Affecting Amount of Air Entrainment

The manufacture of air entrained concrete is complicated by the fact that the amount of air entrainment in a mix is affected by many factors; the important ones are:

(a) The type and quantity of air entraining agent used.

(b) Water/cement ratio of the mix.

(c) Type and grading of aggregate.

(d) Mixing time.

(e) The temperature.

(f) Type of cement.

(g) Influence of compaction.

(h) Admixtures other than air entraining agent used.

The effect of air entrainment on the properties of concrete

Air entrainment will affect directly the following **three** properties of concrete

(a) Increased resistance to freezing and thawing.

(b) Improvement in workability.

(c) Reduction in strength.

Resistance to freezing and thawing

The greatest advantage derived from the use of air entrained concrete is the high resistance of hardened concrete to scaling due to freezing and thawing. It is found that when ordinary concrete is subjected to a temperature below freezing point, the water contained in the pore of the concrete freezes. It is well known that the volume of ice is about 10 per cent higher than the corresponding volume of water. Hence, the ice formed in the pores of hardened concrete exerts pressure. The cumulative effect of this pressure becomes considerable, with the result that surface scaling and disruption of concrete at the weaker section takes place. Similarly, surface scaling and disruption also takes place in plain concrete when subjected to the action of salt used for deicing purpose. Similar pattern of failure of plain concrete is also noticed in concrete structures at the tidal zone and spray zone. It has been firmly established that air entrainment in concrete increases the resistance by about three to seven times in such situations.

Effect on workability

The entrainment of air in fresh concrete by means of air entraining agent improves workability. It was seen that the placeability of air entrained concrete having 7.5 cm slump is superior to that of non-air entrained concrete having 12.5 cm slump. This easier placeabilityof a lower slump should be recognized by the people concerned with concrete construction in difficult situations. Better placeability of air entrained concrete results in more homogeneous concrete with less segregation, bleeding and honeycombing. The concrete containing entrained air is more plastic and 'fatty' and can be more easily handled than ordinary concrete. The pump ability of the mix also increases enormously.

Effect on Strength

It can be generally stated that air entrainment in concrete reduces the compressive strength of concrete. But when the process is applied properly, taking advantage of the benefits accrued on account of air-entrainment, little or no loss of strength should take place and it is even possible that under certain circumstances a gain of strength may be possible. It is true that at a given water/cement ratio, an increase in air content results in loss of strength, but the air entrainment enables reduction of water/cement ratio and sand content, for the given workability, thereby regaining most of not all the lost strength.

Incidentally air entrainment will also affect the properties of concrete in the following ways:

(a) Reduces the tendencies of segregation.

(b) Reduces the bleeding and laitance.

(c) Decreases the permeability.

(d) Increases the resistance to chemical attack.

(e) Permits reduction in sand content.

(f) Improves placeability, and early finishing.

(g) Reduces the cement content, cost, and heat of hydration.

(h) Reduces the unit weight.

(i) Permits reduction in water content.

(j) Reduces the alkali-aggregate reaction.

(k) Reduces the modulus of elasticity.

MINERAL ADMIXTURES (or) POZZOLANS

Mineral admixtures are finely divided siliceous materials which are added to concrete in relatively large amounts, generally in the range 20 to 70 percent by mass of the total cementitious material.

The best pozzolans in optimum proportions mixed with Portland cement improves many qualities of concrete, such as:

(a) Lower the heat of hydration and thermal shrinkage;

(b) Increase the water tightness;

(c) Reduce the alkali-aggregate reaction;

(d) Improve resistance to attack by sulphonate soils and sea water;

(e) Improve extensibility;

(f) Lower susceptibility to dissolution and leaching;

(g) Improve workability;

(h) Lower costs.

Types of Mineral Admixtures

Artificial pozzolans

Fly ash, Blast furnaces slag, Silica fume, Rice husk ash, Metakaoline and Surki.

Natural pozzolans

Clay & shale, Opaline chests, Diatomaceous earth, Volcanic tuffs and Pumicites

FLY ASH ("PULVERIZED FUEL ASH" OR "PFA")

The finely divided residue that results from the combustion of coal and that is transported by flue gases from the combustion zone to the particle removal system. (or)

Fly ash is finely divided residue resulting from the combustion of powdered coal and transported by the flue gases and collected by electrostatic precipitator.

Fly ash is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. Ash which does not rise is termed bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (Si02) (both amorphous and crystalline) and calcium oxide(CaO).

Chemical composition

Fly ash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. In consequence, fly ash is a heterogeneous material. SiO_2, Al203, Fe203 and occasionally CaO are the main chemical components present in fly ashes. The mineralogy of fly ashes is very diverse. The main phases encountered are a glass phase, together with quartz, mullite and the iron oxides hematite, magnetite . The Ca-bearing minerals anorthite, gehlenite, akermanite and various calcium silicates and calcium aluminates identical to those found in Portland cement can be identified in Ca-rich fly ashes.

Classification of fly ash

ASTM broadly classifies fly ash into two classes.

Class F: Fly ash normally produced by burning anthracite or bituminous coal, usually has less than 5% CaO. Class F fly ash has pozzolanic properties only.

Class C: Fly ash normally produced by burning lignite or sub-bituminous coal. Some class C fly ash may have CaO content in excess of 10c%o. In addition to pozzolanic properties, class C fly ash also possesses cementitious properties.

ass F Fly Ash	**ass C Fly Ash**
rived from anthracite or bituminous coals m eastern US	rived from lignite or bituminous coals from western US rticularly) Wyoming and Montana)
zzolanic reaction slower rate of reaction than ass C fly ash	zzolanic and hydraulic reactions typically faster rate reaction than Class F fly ash
pical composition: 0% CaO, >50% SiO2 '	emical composition: 0% CaO, 30-50% SiO2

Physical Characteristics of Fly Ash

1. Mainly solid spheres with some cenospeheres (hollow) or plerospheres (hollow spheres containing smaller spheres)
2. Particle size - 5-20 gm
3. Surface area - 300-500 m2/kg
4. Density - 540-860 kg/m3
5. Specific gravity - 2.2-2.4
6. Color ranges from off - white to light gray.

Effect of fly ash on fresh concrete

Good fly ash with high fineness, low carbon content, highly reactive forms only a small fraction of total fly ash collected. The ESP fly ash collected in chambers I and II are generally very coarse, non-spherical particles showing large ignition loss. They can be called coal ash rather than fly ash.

Such fly ash (coal ash) is not suitable for use as pozzolan and they do not reduce the water demand.

Use of right quality fly ash, results in reduction of water demand for desired slump,with the reduction of unit water content, bleeding and drying shrinkage will also be reduced. Since fly ash is not highly reactive, the heat of hydration can be reduced through replacement of part of the cement with fly ash.

Effects of fly ash on hardened concrete

Fly ash, when used in concrete, contributes to the strength of concrete due to its pozzolanic reactivity. However, since the pozzolanic reaction proceeds slowly, the initial strength of fly ash concrete tends to be lower than that of concrete without fly ash. Due to continued pozzolanic reactivity concrete develops greater strength at later age, which may exceed that of the concrete without fly ash.

The pozzolanic reaction also contributes to making the texture of concrete dense, resulting in decrease of water permeability and gas permeability. It should be noted that since pozzolanic reaction can only proceed in the presence of water enough moisture should be available for long time. Therefore, fly ash concrete should be cured for longer period. In this sense, fly ash concrete used in under water structures such as dams will derive full benefits of attaining improved long term strength and water-tightness.

SILICA FUME

Definition:

A very fine pozzolanic material composed mostly of amorphous silica produced by electric arc furnaces as a by-product of the production of elemental silicon or ferrosilicon alloys.

Silica fume, also known as micro silica, is an amorphous (non-crystalline) polymorph of silicon dioxide, silica.

It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete.

Silica Fume Properties

Physical

1. Very small, spherical particles
2. Particle size - 0.1-0.3 pm
3. Surface area - 15,000-25,000 m2/kg
4. Density - 130-430 kg/m3
5. Specific gravity - 2.2
6. Generally dark gray in color

Chemical

1. 85-98% SiO_2
2. SiO_2 content dependent upon alloy

Production

Silica fume is a by product in the carbo thermic reduction of high-purity quartz with carbonaceous materials like coal, coke, wood-chips, in electric arc furnaces in the production of silicon and ferrosilicon alloys

Available forms

1. Undensified forms with bulk density of 200-300 kg/cum
2. Densified forms with bulk density of 500-600 kg/cum
3. Micro-palletized forms with bulk density of 600-800 kg/cum
4. Slurry forms with density 1400 kg/cum
5. Slurry is produced by mixing undensified micro silica powder and water

Properties of Fresh Concrete using Silica fume

Workability

1. Reduced Workability
2. Water demand increases in proportion to Silica fume added.
3. Water demand is 1% for every 1% 'replacement of cement.
4. Lower Slump & more cohesive mix.

Bleeding & Segregation

✓ Bleeding is reduced as Silica fume particles find their way in between two cement grains.

✓ Segregation is reduced has the concrete mix is more cohesive due to increase in number of solid to solid contact points.

Time of Set

Test results have shown that the initial setting time and final setting time is not greatly influenced. The increase may be 30 min or so.

Plastic Shrinkage

Fresh concrete which is placed is subjected to surface cracking Know as plastic shrinkage. Since Silica Fume concrete show no bleeding, fresh concrete is subjected to plastic shrinkage. Precaution should be taken as per normal concrete

Properties of Harden concrete

Drying Shrinkage:

Drying shrinkage tests by different researcher show that long term shrinkage of concrete is not affected significantly by the addition of Silica Fume.

Creep

Creep of concrete is inversely proportion to strength of concrete. Since Silica fume is highly pozzolonic material, the creep of concrete containing silica fume will be lower than corresponding Portland cement concrete.

Strength

1. Concrete containing Silica Fume showed outstanding characteristics in development of strength.
2. Strength of 62 -80 MPa can be easily achieved.
3. If Silica Fume is used as an addition, there is no deleterious effect on early strength and noticeable strength increase is recorded during the 3 to 28 days moist curing period when most of the pozzolonic reaction takes place.
4. Silica fume forms backbone of high performance concrete due to early high strength properties.

GROUND GRANULATED BLAST FURNCE SLAG(GGBS) (or) SLAG CEMENT

Ground granulated blast-furnace slag is a non-metallic product consisting essentially of silicates and aluminates of calcium and other bases.

- Possesses good latent hydraulic cementing properties
- Slag is the residue from metallurgical
- Processes, either from production of metals from ore or refinement of impure metals.
- The form of slag used in concrete comes from the production of iron from ore.
- Has been used in concrete for > 100 years
- About 70-80% the cost of cement
- Typical cement replacement values 20-70%.

Slag Properties

Chemical composition

- Calcium oxide 30-45%
- Silicon dioxide 30-38%
- Aluminium oxide 15-25%
- Ferrous oxide 0.5-2.0

Physical

1. Particle size < 45)um
2. Surface area - 400-600 m2/kg
3. Density 1050-1375 kg/m3
4. Specific gravity - 2.9
5. Angular particle shape
6. Generally, white to off-white color

Performance of GGBS in concrete

Fresh concrete

The replacement of cement with GGBS will reduce the unit water content necessary to obtain the same slump. This reduction of unit water content will be more pronounced with increase in slag content and also on the fineness of slag. This is because of the surface configuration and particle shape of being different than cement particle. In addition; water used for mixing is not immediately lost, as the surface hydration slag is slightly slower than that of cement.

Reduction of bleeding is not significant with slag of 4000 sqcm/g fineness. But significant beneficial effect is observed with slag fineness of 6000 sqcm/g and above.

Hardened concrete

Exclusive research works have shown that the use of slag leads to the enhancement of intrinsic properties of concrete in both fresh and hardened conditions. The major advantages recognized are

1. Reduced heat of hydration.
2. Refinement of pore structures.
3. Reduced permeability to the external agencies.
4. Increased resistance to chemical attack.

Rice Husk Ash:

Rice husk ash is obtained by burning rice husk in a controlled manner without causing environmental pollution. When properly burnt it has high Sio2 Content and can be used as a concrete admixture.

It has high pozzolonic characteristics and contributes high strength and high impermeability of concrete.

It essentially consists of

1. Amorphous silica (90%SiO_2).
2. Carbon (5%)
3. K_2o (2%)

The specific surface of RHA is between 40-100m^2/g. The particle size is 10-75um.

The rice husk ash particles have complex shapes reflecting their plant origins and they therefore have high water demand unless inter ground with clinker so as to breakdown porous structure.

To achieve adequate workability as well as high strength the use of super plasticizer may be necessary.

CONCRETE MIX PROPORTIONING

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible**, is termed the concrete mix design**. The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states, namely **the plastic and the hardened states.** If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance.

The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour. The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, thus the aim is to produce as lean a mix as possible. From technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete, and to evolution of high heat of hydration in mass concrete which may cause cracking.

The actual cost of concrete is related to the cost of materials required for producing a minimum mean strength called characteristic strength that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the quality control adds to the cost of concrete. The extent of quality control is often an economic compromise, and depends on the size and type of job. The cost of labour depends on the workability of mix, e.g., a concrete mix of inadequate workability may result in a high cost of labour to obtain a degree of compaction with available equipment.

Concept of Mix Design

Workability of the mass is provided by the lubricating effect of the paste and is influenced by the amount and dilution of paste. The strength of concrete is limited by the strength of paste, since mineral aggregates with rare exceptions, are far stronger than the paste compound. Essentially the permeability of concrete is governed by the quality and continuity of the paste, since little water flows through aggregate either under pressure or by capillarity. Further, the predominant contribution to drying shrinkage of concretes is that of paste.

Since the properties of concrete are governed to a considerable extent by the quality of paste, it is helpful to consider more closely the structure of the paste. The fresh paste is a suspension, not a solution of cement in water.

The more dilute the paste, the greater the spacing between cement particles, and thus the weaker will be the ultimate paste structure. The other conditions being equal, for workable mixes, the strength of concrete varies as an inverse function of the water/cement ratio. Since the quantity of water required also depends upon the amount of paste, it is important that as little paste as possible should be used and hence the importance of grading.

TYPES OF MIXES

Nominal mixes:

In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. **These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes.** These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

Standard mixes:

The nominal mixes of fixed cement-aggregate ratio (by volume) vary **widely in strength and may result in under- or over-rich mixes.** For this reason**, the minimum compressive strength has been included in many specifications.** These mixes are termed standard mixes.

IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter **M refers to the mix** and the **number to the specified 28 day cube strength** of mix in N/mm^2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

Design Mixes:

In these mixes the **performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete,** except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30 N/mm^2. No control testing is necessary reliance being placed on the masses of the ingredients.

Significance:

The object of concrete mix design is to find the proportions in which the concrete materials cement, water, fine aggregate and coarse aggregate should be combined in order to provide the specified strength, workability and durability and possibly meet other requirements.

Concrete is a composite material and as such its properties are vitally dependent on the amount and properties of the constituent phases. The mix design is thus an essential tool in all aspects of concrete technology. The prime objective of the mix design is to achieve the required functional properties at the minimum cost, under consideration of environmental parameters and planned production technique well developed mix design methods are thus prime tools in securing sustainable industrial concrete construction techniques.

Variables in Proportioning

With the given materials, the four variable factors to be considered in connection with specifying a concrete mix are:

(**a**) Water-Cement ratio

(**b**) Cement content or cement-aggregate ratio

(c) Gradation of the aggregates

(**d**)Consistency

In general all four of these inter-related variables cannot be chosen or manipulated arbitrarily. Usually two or three factors are specified, and the others are adjusted to give minimum workability and economy. Water/cement ratio expresses the dilution of the paste cement content varies directly with the amount of paste. Gradation of aggregate is controlled by varying the amount of given fine and coarse aggregate. Consistency is established by practical requirements of placing. In brief, the effort in proportioning is to use a minimum amount of paste (and therefore cement) that will lubricate the mass while fresh and after hardening will bind the aggregate particles together and fill the space between them. Any excess of paste involves greater cost, greater drying shrinkage, greater susceptibility to percolation of water and therefore attack by aggressive waters and weathering action. This is achieved by minimizing the voids by good gradation.

Exposure Conditions

- **Mild:** Concrete surfaces protected against weather or aggressive conditions except those situated in coastal areas.
- **Moderate:** Concrete surfaces sheltered from severe rain or freezing whilst wet, Concrete exposed to condensation and rain. Concrete continuously under water. Concrete in contact or buried under non-aggressive soil/ground water.
- **Severe:** Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation. Concrete completely immersed in Sea water, surfaces sheltered from saturated salt, air in coastal area
- **Very Severe:** Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions whilst wet.
  - Concrete in contact or buried under aggressive subsoil/ground water.
  - Concrete exposed to coastal environment.
- **Extreme:** Surface of members in tidal zone, members in dried contact with liquid/solid aggressive chemicals.

Approximate Entrapped Air Content

Maximum size of Aggregate(mm)	Entrapped air as% of volume of concrete
10	3.0
20	2.0
40	1.0

Steps to be followed for concrete Mix design

1. Target strength for mix proportion
2. Selection of W/c ratio
3. Selection of water content
4. Calculation of cement content
5. Proportion of volume of coarse and fine aggregate content
6. Mix calculation
7. Mix proportions

Brief steps / Procedure of mix design:

Preliminary Parameters:

1. The grade designation giving the characteristic strength requirement of concrete.
2. The type of cement influences the rate of development of compressive strength of concrete.
3. Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by Is 456:2000.
4. The cement content is to be limited from shrinkage, cracking and creep.
5. The workability of concrete for satisfactory placing and compaction is related to the size and shape of section quantity and spacing of reinforcement and technique used for transportation, placing, and compaction.

Procedure

1. Data required for mix proportioning.
   a) Grade designation.
   b) Type of cement.
   c) Maximum nominal size of aggregate.
   d) Minimum cement content, maximum cement content.
   e) Maximum water cement ratio.
   f) Exposure condition as per Is456:2000.
   g) Maximum temperature of concrete at the time of placing.
   h) Method of transporting and placing.
   i) Early are strength requirements (if required).
   j) Type of aggregates.
   k) Whether an admixture shall or shall not be used.
   l) Types of admixture and condition of use.
   m) Test data for material.

2. Determine the mean target strength from

$$f_{ck}=f_{ck}+1.65S$$

Where f_{ck} = Target average compressive strength at 28 day.
f_{ck} = Characteristic compressive strength at 28days
S = Standard deviation.

From Table 1 select the value of 'S' for grade of concrete.

3. Select water cement ratio from table 5 of IS 456:2000. The ratio should be within the maximum limit given in Table 5.

4. Select the water content for the required workability (slump) and maximum size of aggregate from.

Table of IS 10262-2019. Check for the use of super plasticizes which reduces 20% of the water content.

5. Calculate the cement content from water – cement ratio and water content obtained. The cement content should be checked against the minimum & maximum cement content from the Table 5 of IS 456:2000.With respect to exposure condition.

6. Calculate fine aggregate and coarse aggregate content from Table 3 of IS 10262:2019.

7. Find out the volume of cement, water, aggregate, by using

- volume of concrete as $1m^3$=a
- $$Volume\ of\ cement = \left(\frac{Mass\ of\ cement}{Specific\ gravity\ of\ cement}\right) \times \frac{1}{1000} = b$$
- $$Volume\ of\ water = \left(\frac{Mass\ of\ water}{Specific\ gravity\ of\ water}\right) \times \frac{1}{1000} = C$$
- Volume of all in aggregates (e) = [a-(b+c)]
- Mass of coarse aggregates = e x volume of C.A x S.G of C.A.
- Mass of fine aggregates = e x volume of F.A x S.G of F.A.

8. Determine concrete mix proportions for 1st trial mix.

9. Prepare the concrete according to calculated proportions and cast three cubes of $150mm^3$ size and test them for 28days after curing to know the compressive strength.

Table 5 of IS456:2000: Exposure Condition

Sl No	Exposure	Plain concrete			Reinforced concrete.		
		Minimum cement Content kg/m^3	Maximum Free water Cement ratio	Minimum Grade of concrete	Minimum Cement content	Maximum free water cement ratio	Minimum grade of concrete.
1.	**Mild**	220	0.60	-	300	0.55	M20
2.	**Moderate**	240	0.60	M15	300	0.50	M25
3.	**Severe**	250	0.50	M20	320	0.45	M30
4.	**Very severe**	260	0.45	M20	340	0.45	M35
5.	**Extreme**	280	0.45	M25	360	0.40	M40

Table of workability, slump and compacting factor of concrete with 20 or 40mm maximum size of aggregates

Sl No	Degree Workability	Slump (mm)	Compacting factor	
			Small apparatus	Large apparatus

1	**Very Low (C.F is Suitable)**	-	0.78	0.80
2	**Low**	25-75	0.85	0.87
3	**Medium**	50-100	0.92	0.935
4	**High**	100-150	0.95	0.96

Factors affecting the choice of mix proportions

Compressive strength: It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction. According to Abraham's law the strength of fully compacted concrete is inversely proportional to the water-cement ratio.

Workability: The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.

Durability: The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

Maximum nominal size of aggregate: In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate. However, the compressive strength tends to increase with the decrease in size of aggregate. IS 456:2000 and IS 1343:1980 recommend that the nominal size of the aggregate should be as large as possible.

Grading and type of aggregate: The grading of aggregate influences the mix proportions for a specified workability and water cement ratio. Coarser the grading leaner will be mix which can be used. Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive. The type of aggregate influences strongly the aggregate-cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.

Quality Control: The degree of control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strengths of the mix lower will be the cement-content required. The factor controlling this difference is termed as quality control.

Mix Proportion designations: The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass

<u>Factors to be considered for mix design</u>

• The grade designation giving the characteristic strength requirement of concrete.

• The type of cement influences the rate of development of compressive strength of concrete.

• Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.

• The cement content is to be limited from shrinkage, cracking and creep.

- The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

Degree of Workability and Slump Value and use for which concrete is suitable

Degree of workability	Slump (mm)	Compacting factor		Use for which concrete is suitable
		Small apparatus	Large apparatus	
Very low	–	0.78	0.80	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand-operated machines.
Low	25 – 75	0.85	0.87	Roads vibrated by hand-operated machines. At the more workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration or lightly reinforced sections with vibration.
Medium	50-100	0.92	0.935	At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration.
High	100-150	0.95	0.96	For sections with congested reinforcement. Not normally suitable for vibration, for pumping and tremie placing.
Very high	–	–	–	Flow table test is more suitable.

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REVIEW QUESTIONS

1. Explain the role of admixtures in concrete technology
2. What are chemical admixtures? List the admixtures used in concrete
3. Explain the role of mineral admixture and chemical admixture
4. Explain the role of admixture in concrete making. Write briefly about the accelerators and retarders
5. Explain the role of fly ash as a admixture
6. Bring out the provisions Incorporated in IS 10262:2019 in mix design.
7. What is meant by concrete mix designs? Write the steps involved in the method of mix designs (IS 10262-2019)
8. Define nominal mix, and its types, explain the importance of design mix in the RCC design of structural members
9. Write step by step procedure for IS method of mix design (Preferably flow chart)
10. Design a concrete mix proportioning for the data given below.

Grade designation	: M50
Type of cement	: OPC 43 grade
Type of mineral admixture	: Flyash
Maximum nominal size of aggregate	: 20mm
Minimum cement content	: 320 kg/m^3
Maximum water-cement ratio	: 0.45
Workability	: 100mm (slump)
Exposure condition	: severe
Degree of supervision	: Good
Type of Aggregate	: Crushed angular aggregates
Maximum cement content	: 450 kg/m^3
Chemical admixture type	: Super plasticizers.
Specific gravity of cement	: 3.15
Specific gravity of fine aggregate	: 2.74
Specific gravity of coarse aggregate	: 2.74
Specific gravity of flyash	: 2.20
Specific gravity of admixture	: 1.145

Water absorption of fine aggregate : 0.5%

Water absorption of coarse aggregate : 1.0%

Sieve Analysis:

i) Coarse aggregate: Conforming to Table 2 of IS: 383

ii) Fine aggregate: Conforming to grading zone1 of Table 4 of IS: 383

11. Design a concrete mix proportioning for the data given below.

Grade designation : M20

Type of cement : PPC Ultra tech

Type of mineral admixture : Flyash

Maximum size of aggregate (MSA) : 20mm

Minimum cement content : 320 kg/m^3

Maximum water-cement ratio : 0.45

Workability : 50-75mm (slump)

Exposure condition : Mild

Degree of supervision : Good

Type of Aggregate : Crushed angular aggregates

Maximum cement content : 450 kg/m^3

Chemical admixture type : Not recommended

Specific gravity of cement : 3.05

Specific gravity of fine aggregate : 2.66

Specific gravity of coarse aggregate : 2.68

Water absorption of fine aggregate : 1.15%

Water absorption of coarse aggregate : 0.85%

Sieve Analysis:

i) Coarse aggregate: Conforming to Table 2 of IS: 383

ii) Fine aggregate: Conforming to grading zone II of Table 4 of IS: 383

11. Design a concrete mix proportioning for the data given below.

Characteristic compressive strength at 28 day 25MPa

Maximum size of aggregate (MSA) : 20mm

Degree of workability compaction factor : 0.8 (C.F)

Degree of quality control : Good

Exposure condition : Mild

Degree of supervision : Good

Maximum cement content : 450 kg/m^3

Specific gravity of cement : 3.15

Specific gravity of fine aggregate : 2.60

Specific gravity of coarse aggregate : 2.72

Sand : Zone-III

Assume any other data suitably