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Concrete and its quality

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Chemical and mineral admixtures and methods to produce concrete of needed characteristics are discussed. The concrete mix proportion has an important influence on producing good quality concrete. Typical data of strengths of concrete for different water-cementitious materials ratios with different percentages of fly ash or ground granulated blast furnace slag show that such concretes are comparable made using 43-grade ordinary Portland cement without any fly ash / ground granulated blast furnace slag.

However, when silica fume is used with superplasticiser, the strength of concrete can be increased to 60 to 70 MPa.

The ready-mixed concrete industry in India is growing rapidly. It produces normal grades of concrete using 43-grade OPC and fly ash. In this paper, the important stipulations of ready-mixed concrete-code of practice , to produce good quality concrete, have been highlighted. The Indian ready-mixed concrete code is a starting point and should be used as a guide to produce and supply good quality concrete for concrete constructions.

Quality of concrete depends on the constituent materials, their proportions, mixing, transporting, placing, compaction and curing of concrete. The concrete with proper mix proportion has the needed workability and develops the targeted compressive strength. Efficient concrete mixers are needed to mix the ingredients and to produce a cohesive and workable concrete. Concrete admixtures play an important role in providing the needed workability for transporting and placing the concrete in the formwork. Once the concrete is placed and consolidated by compaction in the formwork, protected and cured properly, it should be a good quality concrete, and is expected to perform satisfactorily in the service life.

Sometimes, a supposedly good quality concrete does not perform satisfactorily in the service life. One of the reasons for such a performance could be the alkali – aggregate reaction. The alkali of cement reacts with the reactive constituents such as reactive silica or reactive carbonate of aggregates in the presence of moisture. This reaction is harmful and eventually the concrete gets distressed and cracked. Corrosion of rebars could be another reason for non-performance.

High workability or pumpable concrete is a cohesive concrete mix that does not segregate while transporting and placing. To achieve this, the concrete-making materials should be properly proportioned. The mix proportions are also responsible for providing the desired workability and 28-day compressive strength of concrete. The slump of concrete is kept as long as it is wanted for transporting and placing , using retarding superplasticisers. The grading of coarse and fine aggregates also plays a useful role in producing a cohesive concrete mix. Pumpable high-workability concrete needs more fine aggregates than ordinary concretes.

The quality of concrete can be judged by its permeability as shown in Table 1.

The Indian ready-mixed concrete industry is growing rapidly, although its estimated market share is only at about 5-10% of the total concrete market. In contrast, in developed countries, ready-mixed concrete occupies 80-90% of the market share. The industry produces normal grades of concrete using 43-grade OPC and fly ash (about 20-25%) from thermal power plants.

Use of fly ash in concrete

Fly ash meeting specifications of IS 456 can be used to produce good quality concrete.[2] Typical characteristics of good quality fly ash are as follows:

- Fineness (Blaine's) : 320 m^2/kg (Min.)
- Lime Reactivity : 4.5 N/mm^2 (Min.)
- Loss on ignition : 5% (Max.)

Fly ash of such quality can be collected from electrostatic precipitators of thermal power stations. In Ropar (Punjab), concrete roads have been built with M40 grade using such a fly ash. The quantity of fly ash was 50% by weight of the total cementitious materials. The chloride ion permeability of the concrete was 550 coulombs ('very low').[3]

In Delhi Metro projects, about 30% fly ash has been added to concrete mixes to produce M35 grade concrete of 'low' permeability. The permeability was tested by measuring the depth of the water permeation. The average depth of water penetration was only 5 mm against the maximum permissible depth of 25 mm according to MORTH specification.[4]

Lowering the cement content in the concrete mix, and replacing it by fly ash, reduces the peak temperature in concrete.[5] Temperature-rise studies on M35 grade concrete using 30% fly ash in Delhi Metro project suggest lowering of temperature by 8^{o}C when about 84 kg cement was replaced with fly ash.

There are some professionals who apprehend that, corrosion of reinforcement can take place in reinforced concrete construction because of the use of fly ash. This apprehension stems from the notion that alkalinity of fly ash concrete is inferior in providing passivation to rebars. This is not true, since the alkalinity of fly ash concrete does not become less, as pH of concrete was found to be in the range of 12.8 to 12.9 at 90 days, using about 20-30% fly ash in concrete.[6] The joint studies by National Council for Cement and Building Materials (NCB) and The Central Electrochemical Research Institute (CECRI), on M20 and M30 grades of concrete have confirmed corrosion free reinforcements in concrete made of PPC after 12 months' of exposure in marine environment.[7]

In self-compacting concrete (SCC), large quantities of fly ash are needed to make the concrete mix cohesive. As much as 31-37% fly ash have been used to produce quality self-compacting concrete mixes.[8,9] The quality is 'good', when the mix is cohesive and spreads around the reinforcements and corners of the formwork uniformly. The P-C (polycarboxylic ether) based superplasticiser and a viscosity modifying agent make the concrete workable and non-segregating.

Table 1 . Chloride Ion permeability of concrete (As per ASTM C 1202[1])

Sl. No.	Charge passed (Coulombs)	Chloride ion permeability
1	> 4000	High
2	2000 – 4000	Moderate
3	1000 – 2000	Low
4	100 – 1000	Very low
5	< 100	Negligible

Table 2. Chemical compositions of ground granulated blast furnace slag

Chemical constituents (%)	Slag from Durgapur Steel Plant	Slag from Visakhapatnam Steel Plant
SiO_2	33.79	33.20
$Al_2 O3$	20.73	18.30
$Fe_2 O3$	1.12	0.60
CaO	31.06	32.90
MgO	11.23	11.00
SO_3	0.10	1.00
S	0.14	0.70
MnO	0.31	0.43
$Na_2 O$	0.25	0.21
K_2O	0.59	0.91
Cl	0.016	0.006

Use of ground granulated blast furnace slag in concrete

The ground granulated blast furnace slag (GGBS); a mineral admixture can be used in concrete. Since GGBS is a by-product from steel production, its quality is generally good and consistent (Table 2).

This fine material (Blaine's fineness can be around 300 m^2/kg or more) has been used to produce good quality durable concrete. The GGBS reacts with $Ca(OH)_2$ liberated due to cement hydration. The reaction is similar to that seen with fly ash in concrete. For aggressive soil and groundwater, combination of this mineral admixture and OPC are preferred over only OPC in concrete. The studies on concrete with Portland slag cement containing 50-65% GGBS show the quality of concrete to be good. Concrete (M20 grade) using different percentages of GGBS have 'low' and 'very low' chloride ion permeability (Table 3), according to the criteria given in Table 1.

The test results further point out that as the percentage of GGBS increases in concrete, the chloride ion permeability decreases.

To resist harmful alkali-silica reaction, use of more than 50% GGBS in concrete has been recommended[11]. In Koteshwar (in Uttarakhand) hydroelectric project, Portland slag cement with 55% GGBS has been used to build the concrete dam. The quality of mass concrete has been found to be satisfactory. The grade of concrete was M15 and the workability of concrete was "medium", 40-50 mm slump.

Table 3. Test results on chloride ion permeability of concrete[10]

No.	Concrete with PSC having different % of ggbs	Test Results	
		Charge passed (Coulombs)	Chloride ion permeability based on Table 1
1	50	959	Very low
2	54	1051	Low
3	60	983	low
4	65	566	Very low
5	50	1423	Low
6	54	1254	Low
7	60	1056	Low
8	65	576	Very low

M40 grade concrete, Cement = 360-380 kg/m^3
W/c = 0.45, Slump = 170 mm, MSA = 20 mm

High-workability (100-150 mm slump) M40 grade concrete with 70% GGBS has been used to produce good quality concrete for piles in coastal areas in Gujarat. Because of high workability, the fine aggregate content was high at 41%, and because of more fines, no bleeding and segregation were noted in the concrete. The concrete mix proportions used in the piles is shown below:

Grade of Concrete : M40

Maximum size of aggregate : 20 mm

Workability of concrete : 100-150 slump (after 1 hour)

Mixture proportions, kg/m^3

Ordinary Portland cement (53 grade) : 147

Ground granulated blast furnace slag : 343

Water : 170

Coarse aggregate : 1044

Fine aggregate : 720

Superplasticiser : 4

Use of silica fume in concrete

Silica fume (5-10% by weight of cement) is essential to produce high-strength abrasion-resistant concrete. This highly reactive material is a by-product of ferrosilicon industries with fineness greater than 15,000 m^2/kg. This material is being imported from Australia and Norway, and is available through Indian suppliers.

Kinzua dam (in USA) repaired with silica fume concrete presents good performance even after 10 years[12]. Both superplasticiser and silica fume were required to produce high-strength high-performance abrasion-resistant concrete for the intake structures and spillways in the hydroelectric projects. Typical characteristics and concrete mixture proportions for the spillway of Tehri hydroelectric project are as follows:

Grade of Concrete : M60

Maximum size of aggregate : 20 mm

Workability of concrete : 105 mm slump

Mixture proportions, kg/m^3

Ordinary Portland cement (53 grade) : 470

Water : 155

Fine aggregate : 514

Coarse aggregate : 1272

Superplasticiser : 10.7

Silica fume : 38

This data points to the use of 2.3% superplasticiser and 8% silica fume to produce high-workability high-strength concrete.[13]

Concrete mix proportions

Concrete mix proportions have a large influence on the quality of concrete. The water-cement ratio or the water-cementitious materials ratio controls the 28-day compressive strength of concrete. The strength of concrete is also dependent on the strength of cement.

The quantity of fly ash or GGBS influences the cohesiveness and quality of fresh and hardened concrete. About 25 % fly ash or 45 % GGBS are needed to produce cohesive and workable mix. Naphthalene – based superplasticiser (about 1-2% by weight of cement or by weight of cementitious materials) is required with fly ash or GGBS to develop the desired workability and 28-day compressive strength. Typical correlation between w/c ratio and 28-day compressive strength of concrete with different percentages of fly ash and GGBS is shown in Figure 1. The figure indicates that the data on 28-day compressive strength of concrete for different water/cementitious materials ratio for 55% and 65% GGBS in Portland slag cement and concrete with 30 and 35% fly ash. The strengths compared with those of the concrete made using 43-grade OPC and without any fly ash or GGBS.

In a normal concrete with 20 or 40 mm maximum size of aggregate the quantity of fine aggregate needed is 30-35% (% by weight of total aggregate). For high workability pumpable concrete, (about 100-150 mm slump) however, about 40% fine aggregate by weight of total aggregate are needed.

The ready-mixed concrete

The ready-mixed concrete (RMC) manufacturers are poised to supply concrete as needed by the buyer. They use good quality locally available materials, so the supplied concrete is as good as possible. However, according to the Indian Code of Practice IS4926 [14], the buyer needs to supply certain information to the manufacturer, for example, the grade of concrete , workability of concrete required and the environmental condition to which the concrete will be exposed. The producers use OPC, fly ash and superplasticiser in the right proportions to achieve the workability and 28-day compressive strength of concrete.

For hot weather concreting, the supplier of RMC uses a retarding superplasticiser, to provide longer setting time of concrete, so that the concrete can be placed comfortably. The quality of fly ash added should conform to IS 456. The fly ash concrete is more resistant to aggressive environments than concrete without any fly ash. However, such concrete needs to be cured for longer time.

RMC units have two options for supplying concrete; designed mixes and prescribed mixes. In case of designed mixes, the producer takes the responsibility for selecting the concrete mix proportions for the needed performance, whereas for the latter, buyer specifies the concrete mix proportions and the supplier of RMC is not responsible for workability and the 28-day compressive strength of concrete. Sometimes, the concrete admixture and the cement specified by the buyer are incompatible. Therefore, it is always advisable that the producer and the buyer's clarify the compatibility features, workability and 28-day compressive strength of the concrete.

The RMC code IS 4926 provides guidelines for quality control of concrete. The quality control process has been divided into three components, "Forward Control", "Immediate Control" and "Retrospective Control'. Although the RMC companies have latest generation batching and mixing equipment, regular calibration and plant maintenance are required for quality production. Forward Control includes control of purchased material quality, materials storage, mix design and mix design modification, plant maintenance, transfer and weighing equipment and plant mixers and truck mixer . The system is designed to ensure that material and the mix design result in good quality concrete. Controls over moisture content of the aggregates and grading of aggregates are important to achieve the desired workability and 28-day compressive strength of concrete.

The RMC companies face difficulties in hot weather with slump loss, as the needed slump at the supply point is not achieved. Often adding a small quantity of admixture and water could restore the workability, but

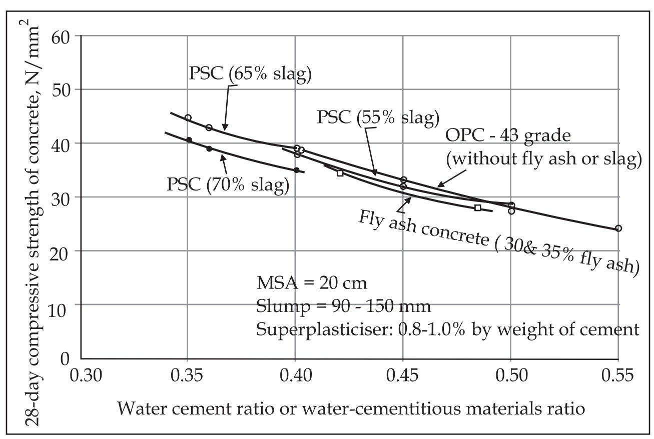

Figure 1. Typical relationship between w/c ratio or water-cementitious materials ratio and 28-day compressive strength of concrete

no guideline is available in the ready-mixed concrete code IS 4926.

The "Immediate Control" includes production control and product control. Each load of concrete is needed to be inspected before dispatching and unloading. Continual workability control is recommended during production. Random sampling of concrete is specified to test the workability. It is important to keep the water-cement ratio as optimised during the mix design to achieve the desired characteristic strength of concrete. The role of chemical admixture therefore becomes important to preserve the needed workability and 28-day compressive strength of concrete.

The "Retrospective Control" is associated with 28-day compressive strength of concrete, because it is not a property that can be measured ahead of or during manufacturing. However, laboratory data on cube tests are precursors to achievable properties. Also for OPC concrete, the accelerated curing method according to IS 9013 helps estimate on the probable 28-day compressive strength of concrete.[15]

Conclusions

Mineral admixtures such as fly ash and ground granulated blast furnace slag in concrete and chemical admixture that superplasticise a mix produce quality concrete that are resistant to aggressive environments. The quality of such concrete is tested by chloride ion permeability test and has been found to be good with permeability being 'low' and 'very low'. The heat of hydration of concrete using fly ash and GGBS is less than that of concrete with only OPC. Therefore the temperature – rise in mass concrete is also 'low'. The pH of concrete made with Portland Pozzolan Cement (PPC) containing fly ash has been observed to be around 12.8 at 90 days. Studies suggest no corrosion of reinforcements of such concretes even after 12 months' of marine exposure. Good quality concrete containing 55% GGBS has been successfully used to build concrete dam and combat alkali-silica reaction in concrete. In Indian scenario, ground granulated blast furnace slag is the safest option to mitigate alkali – silica reaction in concrete. High workability M40 grade with 70% GGBS has been used to produce good quality concrete for the concrete piles in marine environment. For producing high-strength concrete that is M60 grade and above, 5-10% silica fume is required with 53-grade OPC and a superplasticiser. The concrete mix proportions have a large influence on the quality of concrete. Typical correlations between w/c ratios and 28-day compressive strengths of concrete with different percentages of fly ash and GGBS point out that such mixes are comparable to those made with 43-grade OPC and without any fly ash or GGBS.

The Indian ready-mixed concrete manufacturers are well prepared for producing and supplying good quality concrete using OPC, fly ash and super plasticisers. The Indian ready-mixed concrete code of practice should be used as a guide to produce and supply good quality concrete for building durable concrete structures.

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