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# Mix Design of High Early Strength Concrete (70 MPa) for 4 Hours of Hot Water Curing

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**Abstract—***Concrete is the most versatile (composite) construction material available. Contrary to the construction of a steel structure, construction with concrete is a slow process as the hardening and strength gain take few days of time to make the beam or column a load bearing structural element. If the hardening process can be accelerated, the construction speeds up. Like in steel structures, if pre-fabricated (pre-cast) structural members are used, the construction quickens. High strength concrete reduces the cross-sections of structural elements, so members will become lighter and easier to handle for movements / relocation. This is where, there is a great demand for high strength and high early strength concretes.*
*Many researchers have attempted to make high early strength concretes with different chemical and mineral admixtures like quartz flour and High range water reducing admixtures, but here the attempt was made to use the materials available locally, so that the results can be utilized in the field directly in new construction works.*
*In this project, an attempt was made to design a concrete mix capable of attaining a high early strength of 70MPa with 4 hours of hot water (at 100$^{o}$C) curing after de-moulding the cubes. The mixes were prepared with varying proportions of silica fume / fly ash, super plasticizer and rapid hardening solution dosages and W/C ratios. The mixes were checked for compressive strengths after 7-day normal curing too.*
*The base mix is designed for M55 grade and then the mix proportions were changed from there to increase / accelerate the early strength. The chosen mix is capable of attaining a strength of more than 70MPa either through 4 hours of hot water curing or 7 days of normal curing.*

**Keywords***: High early strength, pre-cast, admixtures, pozzolanas, durability.*

## 1. INTRODUCTION

In all the developed and developing countries there is a lot of need for infrastructure development. The rate at which the construction industry is progressing itself is a measure of the development of a country. In our country the per capita concrete consumption is nearing 1 ton /year. To meet the changing or increasing demand we are moving towards rapid construction practices like pre-cast and pre-stressed concrete wherever there is a chance. Wherever there is a need for pre-stressed and pre-cast structural members there is a need for high strength and high-early-strength concrete. This is where the admixtures come into play. During the last decade, developments in admixtures and mixing and placing methods have made it possible to produce concretes with higher strengths (70-100 Mpa).

High strength concrete has compressive strengths of up to 100 Mpa as against conventional concrete which have compressive strengths of less than 50Mpa. Concrete having compressive strength greater than 200Mpa is classified as ultrahigh-strength concrete.

The ingredients of high-strength concrete are the same as those used in conventional concrete with the addition of one or two admixtures, both chemical and mineral. However, there are two crucial aspects to be considered while deciding upon the ingredients to be used. The first relates to the use of an extremely low water cement ratio and the second to the use of a proper mix in order to produce minimum or no voids. A proper mix can be obtained using a particle packing method. It is essential to use a plasticizing chemical admixture to produce high-strength concrete. Generally water reducing admixtures are used.

The mix reduces high paste volume, which often leads to shrinkage and high evolution of heat of hydration, besides increasing the cost. The substitution of cement by supplementary cementitious materials such as mineral admixtures partially introduces favourable behaviour with respect to the above mentioned defects and incidentally reduces cost. The materials that are commonly used are flash, ground granulated blast-furnace slag, silica fume, rice husk and metakaolin. The use of such properties not only improves the properties of fresh concrete but also enhances the long term durability characteristics.

High strength concrete essentially has low water-binder ratio. A value of 0.3 is suggested as the boundary between normal and high strength concrete. For ultra high strength concrete this value is further reduced by the use of high-range water-reducing admixtures. Although the compressive strength of concrete has been steadily improving in recent times, the potential to increase it further has become evident with its use in columns of high rise buildings and long span bridge girders all over the world.

## 2. COMPOSITION OF HIGH STRENGTH CONCRETE

The composition of high strength concrete aims at using all the constituents of concrete fully. In ordinary concrete, not all the cement that is added gets hydrated. Hence some form of mineral admixture is added in high strength concrete. This acts as a cementitious material and hence reducers water binder ratio.

Two examples of the composition of 200-Mpa concrete, taken are from Sauzeat et al (1996) and Aitcin and Richard (1996). The key ingredients of this type of concrete are the following.

1. Lower water binder ratio
2. Large quantity of silica fume and/or fine mineral powder
3. Aggregates containing fine sand with good particle packing characteristics.
4. High dosage of super plasticizers

## 3. MICROSTRUCTURE OF HIGH STRENGTH CONCRETE

A number of microstructure studies have revealed dense distributions of particles in high strength concrete as compared to those in conventional concrete Based on these observations, the following conclusions have been made.

1. The material is more homogenous on a millimetre scale.
2. No pronounced transition zone between the sand and the paste is seen.
3. Low porosity (1-3%)
4. Proportionally lower percentage of capillary porosity (10% of total porosity)

These features lead to low water absorption, gas permeability, and chloride diffusivity.

## 4. SCOPE OF THIS WORK

Scope of the work is limited to O.P.C-53, S.P. 430, Rapid Hardening Solution, NTPC paravada Fly ash and Silica Fume. Hot water curing for 4 hours and Normal curing for 7 days only, 28 days strengths were not tested.

- Present study is restricted only to test the compressive strength of the concrete mix designed with different admixtures.
- Most of the mixes were initially cast in 10 cm X 10cm X 10 cm cube moulds.
- The concrete cubes (10 cm) which yielded higher strengths of the order of 60 MPa are considered for casting in 15 cm cube moulds.
- Volume of coarse aggregates as percentage of total volume of aggregate is fixed at 46% for all the mixes (with all admixtures) at all W/C ratios.
- The nominal maximum size of aggregate was mixed to be 10 mm due to the constrained of 10cm cube mould.

## 5. MATERIAL CHARACTERIZATION

Cement properties:

Compressive strength: 55.8 MPa

Initial setting time: 50 minutes

Final setting time: 8 hours 30 minutes

Consistency: 34%

Soundness test value: 5 mm

Flyash Properties:

Class F – Flyash

Percentage retained on 45 microns = 6 %

Silica Fume Properties:

Percentage of Silica > 90 % (Specification)

Percentage retained on 45 microns = 3 %

Aggregate Properties:

Fine aggregate:

Specific gravity of Sand = 2.74

Sand conforming to Zone – II

Coarse aggregate:

Specific gravity of coarse aggregate = 2.68

Water: Drinking water (potable water)

Super-plasticizer used is an admixture based on sulphonated napthalene polymers

Rapid hardening solution composition was unknown.

Different concrete mixes were designed by varying the proportions of water/cement ratio, super-plasticizer dosage, silica-fume / fly-ash dosage and rapid hardening solution dosage and the strength results were recorded and the mixes were further modified / improved and tested again until the desired 70 MPa mix was achieved.

Different mix proportions' strengths after 4 hours of hot water curing are presented here.

Mixes with fly-ash partly replacing aggregate:

Cement: 450 Kg / Cu M of concrete

Water/ Cement ratio = 0.34

C:FA :CA = Cement: Fine Aggregate: Coarse Aggregate

| Fly-Ash (kgs / m3 concrete) | Proportion C : FA: CA | Density (kg/m3) | Compressive strength (MPa) |
|---|---|---|---|
| 11.25 | 1: 2.26: 1.93 | 2285 | 32.69 |
| 22.5 | 1: 2.25: 1.91 | 2407 | 51.03 |
| 33.75 | 1: 2.24: 1.91 | 2379 | 42.02 |
| 45 | 1: 2.23: 1.89 | 2369 | 55.00 |
| 22.5 | 1: 2.25: 1.91 | 2407 | 58.69 |
| 45 | 1: 2.23: 1.89 | 2369 | 41.74 |

Mixes with Silica fume partly replacing aggregate:

Cement: 450 Kg / Cu M of concrete

Water/ Cement ratio = 0.4

| SilicaFume (kgs / m3 Concrete ) | Proportion C : FA: CA | Density (kg/m3) | Compressive strength (MPa) |
|---|---|---|---|
| 112.5 | 1: 2.22 : 1.89 | 2381 | 37.05 |
| 180 | 1: 1.86 : 1.94 | 2333 | 26.56 |
| 90 | 1: 2.06: 1.94 | 2494 | 38.56 |
| 135 | 1: 1.84: 1.94 | 2361 | 33.33 |
| 45 | 1: 1.57: 1.33 | 2420 | 45.44 |
| 112.5 | 1: 2.22: 1.89 | 2350 | 32.2 |

Water/ Cement ratio = 0.34

| SilicaFume (kgs / m3 Concrete ) | Proportion C : FA: CA | Density (kg/m3) | Compressive strength (MPa) |
|---|---|---|---|
| 22.5 | 1: 2.25: 1.91 | 2457 | 42.98 |
| 11.25 | 1: 2.27: 1.91 | 2473 | 59.75 |

Mixes with varying Super-plasticizer doses:

(without Fly-ash and Silica Fume)

Cement: 450 Kg / Cu M of concrete

Water/ Cement ratio = 0.34

| Super plasticizer ( litres / 50 kgs of cement) | Proportion C : FA: CA | Density (kg/m3) | Compressive strength (MPa) |
|---|---|---|---|
| 0 | 1: 2.26: 1.9 | 2452 | 33.99 |
| 1.125 | 1: 2.26: 1.9 | 2471 | 60.5 |
| 2.25 | 1: 2.26: 1.9 | 2497 | 49.73 |
| 4.5 | 1: 2.26: 1.9 | 2478 | 39.85 |

Mix with Fly-ash and Super-plasticizer:

Cement: 450 Kg / cu. m. of concrete

Water/ Cement ratio = 0.3

Fly-ash: 22.5 kgs / $m^3$of concrete

Super-plasticizer: 1.125 Litres / 50 kgs of cement

Proportion C: FA : CA = 1: 2.25: 1.92

Density: 2416 Kg/ $m^3$

Compressive Strength: 46.50 MPa

Mixes with Silica Fume and Super-plasticizer combinations:

| W/C | Silica fume (kgs / m3 Concrete | Super plasticizer (ltrs) | Proportion C:FA:CA | Compressive strength (MPa) |
|---|---|---|---|---|
| 0.4 | 11.25 | 2.25 | 1:2.22: 1.89 | 42.12 |
| 0.35 | 45 | 2.25 | 1:1.62: 1.38 | 27.01 |
| 0.3 | 22.5 | 1.125 | 1:2.25: 1.92 | 25.00 |
| 0.25 | 22.5 | 6.75 | 1:2.29: 1.92 | 38.98 |

Mixes with Rapid Hardening Solution:

( Without Silica Fume or Fly-ash)

| R.H.S (liters / 450 Kg Cement) | Proportion C: FA: CA | Density (kg/m3) | Compressive strength (MPa) |
|---|---|---|---|
| 22.3 | 1: 2.27: 1.92 | 2423 | 54.01 |
| 27 | 1: 2.29: 1.92 | 2474 | 57.32 |
| 24 | 1:1.9:1.62 | 2339 | 35.4 |

After studying the above results some more proportions were tried. The final (combination of) proportions that gave desired strength values are presented here.

Mix-1:

Cement: 450 Kg / cu m of concrete

Water/ Cement ratio = 0.34

Fly-ash: 22.5 kgs / $m^3$of concrete

Super-plasticizer: Nil

Proportion C: FA : CA = 1:2.28:1.94

Density: 2480 Kg/ $m^3$

Compressive Strength: **68.4 MPa**

Mix-2:

Cement: 450 Kg / cu m of concrete

Water/ Cement ratio = 0.34

Fly-ash: Nil

Super-plasticizer: Nil

Silica Fume: 11.25 Kgs / $m^3$ of concrete

Proportion C: FA : CA = 1:2.28:1.94

Rapid Hardening Solution: 27 liters / 450 kg cement

Density: 2415 Kg/ $m^3$

Compressive Strength: **76.5 MPa**

## 6. OBSERVATIONS AND CONCLUSIONS FROM THIS WORK ARE

1. Many researchers have used Silica fume up to 33% and Fly-ash up to 50 % by weight of cement but here it was observed that more than 5% by weight of cement didn't contribute much to the "early" strength
2. Super plasticizer is believed to contribute so much to strength as well as to workability while reducing w/c ratio, but it was observed that most of the samples in which sp dosage exceeded 1litre/100kg of cement did not reach high early strength requirement though they contributed to the workability of mixes.
3. When the super plasticizer dosage exceeded 2 litre/100 kg of cement, the samples took much longer time to set, as excess dosage may have acted as a retarder.
4. Rapid Hardening Solution (dosage not exceeding 6litre/100kg of cement) considerably improved the early strengths (as quoted in many research papers). The composition is not known, but the accelerated hydration process and subsequent strength growth is remarkable.
5. The rapid hardening solution also contributed to early setting (as the label says), it facilitated in de-moulding the cubes within 5 hours of casting
6. The rapid hardening solution when used in combination with silica fume and/or fly ash and/or super plasticizer contributed to higher strengths.
7. Rapid hardening solution dosage beyond 6litre/100kg of cement is not advisable as the strength growth falters beyond this dosage.

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