A Comparative Study on Flexural Strength of High Strength Concrete using Silica Fume

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Abstract: *This paper investigates the effect of mineral admixture silica fume in determining the modulus of rupture of high strength concrete. It also aims at comparing the flexural strength using ACI 363R-92 and IS: 516-1959 codes. The high strength concrete specimens were prepared with 8% silica fume and 1% hyper plasticizer using 0.36 w/c ratio. To study the flexural behavior of high strength concrete, prism of size 100x100x500mm were cast and are tested in flexural testing machine for 7, 14 and 28 days strength and the results are compared with reference to codes. The comparative results showed a marginal variation in the properties.*

Keywords: *High strength concrete, Mineral admixture*, *modulus of rupture, flexural strength, silica fume.*

I. INTRODUCTION

High strength concrete (HSC) has compressive strength of up to 100 MPa as against conventional concrete which has compressive strength of less than 50 MPa. 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 concrete with minimum or no voids. A proper mix can be obtained using a proper particle packing method and it is essential to use a plasticizing chemical admixture to produce high strength concrete. Generally, water-reducing admixtures (WRA's) are used. The mix requires high paste volume, which often leads to shrinkage and high evolution of heat of hydration, besides increasing the cost. The addition of supplementary cementitious materials such as mineral admixtures to cement partially introduces favourable behavior with respect to the above mentioned defects and incidentally reduces the cost.

The materials that are commonly used are fly ash, ground granulated blast-furnace slag, silica fume, rice husk ash, and metakaolin. The use of such material not only improves the properties of fresh concrete but also enhances the long term durability characteristics.

High strength concrete essentially has a low water-binder ratio. A value of 0.30 is suggested as the boundary between normal and high-strength concrete. 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. The American Concrete Institute method (ACI 211.4R-93) can be used to proportion both normal and high-strength concrete.

In the building industry, the measurement of certain physical and mechanical properties of concrete is particularly important, such as compressive strength ($f'c$) and modulus of rupture (MOR). The flexural tensile strength at failure is called modulus of rupture. The determination of flexural tensile strength is essential to estimate the load at which the concrete members may crack. As it is difficult to determine the tensile strength of concrete by conducting a direct tension test, it is computed by flexure testing. The knowledge of modulus of rupture is useful in the design of pavement slabs, airfield runways, finding deflections and crack widths as flexural tension is critical in these cases.

The method to determine MOR includes the determination of the flexural strength of concrete from simply supported unreinforced concrete beams, where load is applied to the beam until fracture (also called as third-point load test: the load applied at one third point from either end of the beam and the other two are the supports). Concrete as we know is relatively strong in compression and weak in tension. Direct measurement of tensile strength of concrete is difficult. Neither specimens nor testing apparatus have been designed which assures uniform distribution of the 'pull' applied to the concrete. While a number of investigations involving the direct measurement of tensile strength have been made, beam tests are found to be dependable to measure flexural strength property of concrete.

Okere Chinenye Elizabeth, March 2013 studied that Concrete mix design involves selecting the correct proportions of cement, fine and coarse aggregates and water to produce concrete having the specified properties. Various mix design methods have some limitations. Time, energy and money are sometimes being wasted in order to get the appropriate mix proportions. This work is geared towards formulating a mathematical model for the optimization of modulus of rupture of concrete. With the model, the user needs only to specify the modulus of rupture (MOR) of concrete desired and almost immediately, the computer provides all the possible mix ratios that can yield the desired modulus of rupture of concrete. The model can also produce the modulus if mix proportions are given as well as the optimum value. This model is based on Henry Scheffe"s simplex theory, using a quadratic polynomial and a (4,2) simplex lattice. Statistical tests were used to verify the adequacy of the model. They all agreed to the acceptance of the model.

II. MIX DESIGN

The concrete mix design begins by determining the requirements of the concrete. These requirements take into consideration the weather conditions that the concrete will be exposed to in service, and the required design strength. Many factors need to be taken into account, from the cost of the various additives and aggregates, to the tradeoffs between, the "slump" for easy mixing, placement and ultimate performance. A mix is then designed using Portland cement and other cementitious materials, coarse and fine aggregates, water and chemical admixtures. The results of mix design for M60 grade concrete using silica fume and hyper plasticizer are summarized in Table 1.

Table 1: Mix Design for M-60 Grade Concrete

Grade of Concrete	**M_{60}**
Water cement ratio	0.36
Cement	450 Kg
Fine Aggregate	730 Kg
Coarse Aggregate 20mm 12.5mm	 680 kg 450 kg
Water	160 Litre
Mineral Admixture Silica Fume @ 8%	36 Kg
Chemical Admixture Hyper Plasticizer- CLASSIC SUPERFLOW PC 8860 @ 1%	4.5 Litre
Design Mix Proportions	1:1.62:2.51

III. EXPERIMENTAL PROGRAMME

A. Materials

Finely divided mineral admixtures like Silica Fume (SF) has been widely used in High Strength Concrete. Silica fume is a by-product of the melting process used to produce silicon metal and ferro silicon alloys. Silica fume improves compressive strength, bond strength and abrasion resistance. It reduces permeability and therefore protects reinforcing steel from corrosion. It also combines with calcium hydroxide during hydration of cement to improve concrete durability. As micro filler, the extreme fineness of the silica fume helps to fill the microscopic voids between cement particles thereby reducing permeability and improving the paste to aggregate bonding. The properties of silicafume are given in Table-2

Table 2: Mineral Admixture

Mineral Admixture – SILICA FUME (SF)		
1	Type of material	Amorphous (Non-crystalline material). SiO_2 ranging from 85 to 98%.
2	Obtained as by-product in manufacture of	Silicon, ferrosilicon, quartz and carbon in electric arc furnace.
3	Reactive material content	Silicon dioxide (SiO_2)
4	Additional material	Trace elements

5	Particle size	95 % < 1 micrometer (μm). Approximately 100 times smaller than average cement particle
6	Particle shape	Spherical
7	Bulk density	130 to 430 kg/m^3 (as produced)
8	Specific gravity	2.2
9	Specific surface	15,000 to 30,000 m^2/kg
10	Dosage	5 to 10 % of cement content of a mix
11	Conforming to standards	IS 456:2000(cl: 5.2.1.2), ACI 234R-96, ASTM C 1240, ASTM C 618, AASHTO M 307

Chemical admixtures such as hyper-plasticizers (High Range Water Reducer) increase concrete strength by reducing the mixing water requirement for a constant slump and by disbursing cement particles with or without a change in mixing water content permitting more efficient hydration. The main consideration of using hyper-Plasticizers in concrete is the high fines requirements for cohesiveness of the mix and rapid slump loss. The properties of hyper-plasticizers used are shown in Table 3.

Table 3: Chemical Admixture

HYPER PLASTICIZER (HP) – CLASSIC SUPERFLO PC 8860		
1	Base	Polycarboxylate ether polymer
2	Appearance	Amber coloured liquid
3	Specific Gravity	1.15± 0.01
4	pH value	7±1
5	Solid content	45%
6	Chloride content	Nil (BS:5075)
7	Solubility	Water Soluble
8	Dosage	400 to 1200ml per 100kg Cement (0.4 to 1.2% [V/W])
9	Particle size	0.25 to 0.35 micrometers (μm)
10	Water reduction in concrete	Upto 40%
11	Gives high slump with W/c ratio	< 30%
12	Slump retention (maintain fluidity)	About 4 hours at 35^{o}C
13	Conforming to Standards	IS 456:2000 (cl: 10.3.3), IS: 9103-1999, ASTM C 494 Type B, Type D and Type G.

The value of the modulus of rupture (extreme fibre stress in bending) depends on the dimensions of the beam and manner of loading. The prism size cast is 100 x 100 x 500mm [Fig 1]. The prism mould should be of metal, preferably steel or cast iron and metal should be of sufficient thickness to prevent spreading or warping. The tamping bar should be a steel bar weighing 2kg, 40cm long and should have ramming face 25mm square. Test specimens are stored in water at a temperature of 24° to 30° C for 48 hours before testing. They are tested immediately on removal from the water whilst they are still in a wet condition. The dimension of each specimen should be noted before testing.

B. Workability

Slump test was carried out to measure the mobility or flowability of concrete, and measured in quantitative terms [Fig 2]. Several factors affect the workability of concrete. They relate to the properties of aggregates, cement, water and entrapped air. Workability was mainly affected by aggregates. The properties of aggregates that affect workability include their maximum size, grading type, shape and texture.

The workability of concrete when added with silica fume found to be decreased. By the addition of hyper plasticizer @1% by weight of cementitious material, the workability was improved and a maximum slump of 85mm was achieved.

Fig 1: Prism Mould

Fig 2: Slump test

C. Test conducted

The prism specimens were tested in a flexural testing machine of 1000kN capacity under third-point loading in accordance with IS 516:1959. The load was applied in increments and the load corresponding to first crack and the maximum load reached were noted for each specimen. The specimen is loaded till it fails and the maximum load (P) applied to the specimen during test is noted. After fracture the distance (a) between the crack and nearest support is measured.

The testing of prism is shown in Fig. 3 and the failure pattern of prism is shown in Fig.4.

Fig 3: Testing of Prism Fig 4: Prism Failure pattern

IV. RESULTS AND DISCUSSIONS

Modulus Of Rupture is calculated for ACI code method from the testing of 150mm diameter & 300mm height cylindrical specimen and where as for IS code method from testing of 100 x 100 x 500mm prismatic beam by using compression testing machine and flexural testing machine respectively by using the following equations.

i) ACI Code Method

Modulus of Rupture " fr " = 0.94 √fcu

ii) IS Code Method

Case 1: If a>133mm, then Modulus of Rupture (fb) = WL/BD^2

Case 2: If a<133mm >110mm, then Modulus of Rupture (fb) = $3Wa/BD^2$

[Flexural strength, fcr = 0.7x √fck = 0.7*√60 = 5.42 N/mm2 (Ref: IS 456-2000, Cl:6.2.2)**]**

The flexural strength of the specimen is expressed as the modulus of rupture when "a" is greater than 13.3 cm or when "a" is in between 11.0 cm and 13.3 cm where, a = the distance between the line of fracture and the nearest support b = measured width in cm of the specimen, d = measured depth in cm of the specimen was supported, and P = maximum load in kg applied on the specimen. If "a" is less than 11.0 cm the test result is discarded.

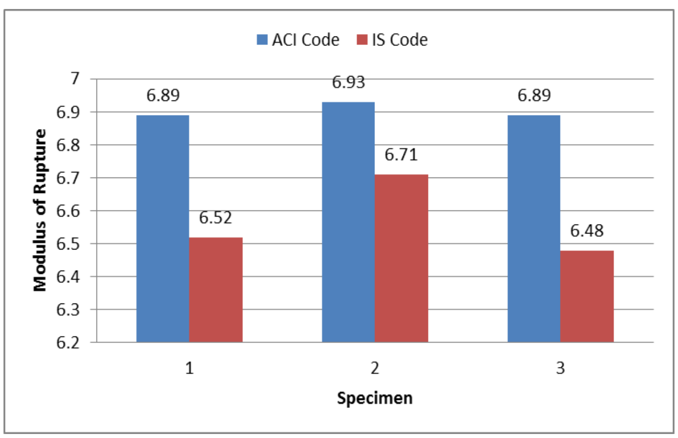

Fig. 5 Modulus of Rupture – ACI Code vs IS Code

V. CONCLUSION

It is observed that while testing, the line of fracture occurs under case-2 and the failure patterns are almost vertical and brittle suddenly with sound of brittleness. From the above test results, it is observed that the value of Modulus of Rupture in ACI code method is varying more from 3.17% to 5.95%, when compared to IS code method.

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