Flexural Behavior of High-Performance Reinforced Concrete Beams

B. Sabharinadh, V. Ranga Rao

Abstract: High performance concrete (HPC) exhibits better properties when compared to conventional concrete. Utilization of pozzolanic materials (Ground Granulated Blast Furnace Slag (GGBS), fly ash and silica fume etc.) in concrete decreases the clinker production. This paper presents the feasibility of pozzolanic materials utilization in HPC, the mix of 60MPa compressive strength was adopted and with water-binder ratio as 0.31 as per standard procedure of ACI-211.4R.91. Percentage of cement in 10,20,30 and 40 was replaced with GGBS. Silica fume was added at 2,4 and 6 percentages to cement by weight as admixture. Compressive and split tensile strengths were determined for HPC after 28 days of curing. Reinforced HPC beams were caste and tested to check failure pattern after 28 days of curing under mid- point, 2-Point and Uniformly distributed loading. Flexure strength, deflection and crack pattern were measured. Better results were observed at 20% GGBS replacement and at 6% silica fume addition for all specimens.

Index Terms: HPC, Flexure strength, loading, Deflection and Crack Pattern.

I. INTRODUCTION

High performance concrete (HPC) is in upper hand in all aspects of strength and mechanical properties than those of conventional concrete. With the addition of silica fume in conventional concrete makes it more capable to perform. HPC has defined compressive strength of 50MPa or above. HPC has been primarily used in bridges, tunnels, nuclear power plants and tall buildings for its strength, durability and high modulus of elasticity. It has also been used in energy absorption capacity, parking garages, agricultural applications, Shotcrete repair and retrofitting jobs. HPC are made with carefully selected high-quality ingredients and optimized mixed designs, batching, mixing, placing should be made suitable to meet highest industry standards.

Typically, such concretes will have a low water-binder ratio of 0.20 to 0.45. Super plasticizers play a vital role in the production of High-performance concrete. Admixture is an essential part of HPC mix.

The behavior of Alccofine based high performance concrete, enhance the mechanical properties of concrete [1]. Alccofine was used as a mineral admixture in concrete mix to increase the initial strength of the concrete than the ordinary concrete [2]. The recycled aggregates (RCA) of 4-16 mm sizes and class F fly ash were used in concrete [3]. To achieve compressive strength of concrete, the water cement ratio of 0.25, 0.3 and 0.35 were used [4]. The experimental investigation on HPC, 12.5mm maximum size aggregates were used to ascertain workability and the mechanical properties of the M80 and M100 grades and to find out partial replacements of silica fume [5]. To improve compressive strength up to 15% replacement of silica fume with cement in HPC. [6]. The partial replacement levels of fly ash (class F) and allcofine on compressive strength and durability properties of concrete [7]. The experimental study was done on the usage of GGBS in the HPC [8]. The guide lines were followed for the selection of the mix proportions of High-strength concrete with combination of cement and fly ash [9]. The experimental investigation was done with High-quantity of Fly ash [10]. In this paper to study, five different mixtures are design for investigation of efficiency of silica fume, GGBS and synergistic effects of these pozzolanic materials on split tensile and compressive strength of concrete in comparing with control mixture or specimens. This paper deals with evaluation of basic properties of compressive strength, split tensile strength of cubes and cylinders, ultimate load, deflection and crack pattern and flexural behavior of reinforced HPC beams respectively by using binder with various properties of GGBS and Silica fume.

II. MATERIALS

A. Cement

Cement is the major engineering material after the extinction of lime in the construction industry. OPC 53 grade cement is normally used to cast the special type of concrete structures. The value of specific gravity of cement is 3.12. The main reason behind considering 53grade cement is because of its specific surface area and fineness makes the process of hydration efficient and provides adequate strength. Before selecting the grade of cement trail mixture which gives the density of 556Kg/m^{3}is adopted by varying the cement sand and cement content.

B. Coarse aggregates

The important parameters of coarse aggregates are its texture, shape and the optimum size. The aggregate strength was an important role in the case of high-performance concrete. The nominal size of the aggregates used were 20mm,10mm and crushed aggregates. The properties are shown in Table I.

Table I: Coarse aggregates

Specific gravity	Bulk density	Water absorption
2.67	1535 kg/m³	0.48

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C. Fine aggregates

The main role of the fine aggregates (sand) is to provide workability and good finishing characteristics of concrete. River sand with a fineness modulus (FM) of about 3.0 is taken as coarse aggregate has been found to be satisfactory for production high compressive strength and good workability. For special strength of 50MPa or greater, FM should be between 2.8 and 3.1.

D. Silica fume

Silica fume is a byproduct of ferrosilicon alloys. The addition of silica fume is reducing the permeability of concrete. It is an effective pozzolanic material Although the slump decreases, the mix remains highly cohesive.

E. Ground Granulated Blast Furnace Slag

GGBS is used as a direct replacement in the basic weight of cement. Replacement levels for GGBS varies from 30% to 80%. In most instances of GGBS use 40% to 50%.

F. Water

The acceptability of water for high-strength concrete is not required major content. Water is lubricating the concrete mix.

G. Chemical Admixtures

High-range water-retarders are needed to ensure that the concrete is easy to place and finishing. Super plasticizer is used to check the early setting problem. The combination of mineral and chemical admixtures is nearly always essential to ensure achievement of the required strength.

III. EXPERIMENTAL WORK

The experimental work was carried out by the basic properties of compressive strength cubes(150×150×150mm) and split tensile strength of cylinders (150mm diameter, H=300mm) respectively by using binders with various proportions of GGBS and silica fume. The experimental work consists of casting and testing of total 64 cubes and 48 cylinders. All specimens were cast with M60 grade concrete. Figure 1 gives the information about the casted cubes and cylinders.

Figure 1: Cube & cylinder Specimens

After performing various tests on cubes and cylinders, Categories 1, 2 and 3 are mentioned for the various mixtures with different percentage in GGBS and Silica fume. It is found that optimum value is obtained for the samples of 80% cement, 20% GGBS and 6% silica fume is the most - effective combination to give optimum results.

A. Mix Design Method

The methodology of formulate an HPC mix design is based ACI 211.4R-93 following phases,

a) Water requirement and air content of conventional concrete based on using a sand under 35% of voids.
   The target strength $F_{ck}= f_{ck}+1.65(s)$
   F_{ck}= target compressive strength
   f_{ck}= characteristics compressive strength
   s= assumed standard derivation is 5N/mm²
b) Strength required is based on maximum size of aggregates.
c) Selection of optimum dry rodded unit weight of coarse aggregates content. Based on ASTM C 29.
d) Water quantity and air content is based on Mix grade of concrete.
e) The recommended maximum water-cement ratio, to achieve different compressive strengths at 7 days, 28 days for a mix made with high-range water-reduction (HRWR).
f) The amount of cement content can be determined by dividing water quantity by water-binder ratio.
g) After determining the fine aggregates of absolute volume.

B. Mix Proportion

The recommended trial mixtures are conducted (workability) the basic mixture of each percentage of chemical admixture. The mix proportions (M60 grade) are shown in Table II.

Table II: Mix proportions

Cement	Fine aggregates	Coarse aggregates	w/c	Chemical admixtures
556 Kg/m^3	630 Kg/m^3	1100 Kg/m^3	0.31	2.78 Kg/m^3

The amount of GGBS and silica fume that is to be taken in three categories and Table 3 show the details of concrete weights of different proportions for M60:

1) In this case taken silica fume as a constant value of 2% and the replacement of GGBS by considering percentage 10%,20%,30% and 40%.
2) Taken silica fume 4% of constant value and the replacement of GGBS by considering percentage 10%,20%,30% and 40%.
3) In this case take 6% of silica fume constant value and the replacement of GGBS by considering percentage 10%,20%,30% and 40%.

Table III: Details of concrete Mix Proportions for M60

Mix Id	Cement	Sand	CA	SF	GGBS
100C0S0G	556	630	1100	0	0
90C2S10G	500.4	630	1100	11.12	55.6
80C2S20G	444.8	630	1100	11.12	111.2
70C2S30G	389.2	630	1100	11.12	166.8

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60C2S40G	333.6	630	1100	11.12	222.4
90C4S10G	500.4	630	1100	22.24	55.6
80C4S20G	444.8	630	1100	22.24	111.2
70C4S30G	389.2	630	1100	22.24	166.8
60C4S40G	333.6	630	1100	22.24	222.4
90C6S10G	500.4	630	1100	33.36	55.6
80C6S20G	444.8	630	1100	33.36	111.2
70C6S30G	389.2	630	1100	33.36	166.8
60C6S40G	333.6	630	1100	33.36	222.4

Note: In all proportions amount of Super plasticizer (2.78), water quantity (175) is same and all quantities are in Kg/m^3.

C. Casting Beams

By taking the optimum values obtained after testing under casted with variation in percentage of materials and constant super plasticizer. The beams are casted with dimension (230mm×300mm and length= 1300mm). The Figure 2 shown as Reinforcement of beam details.

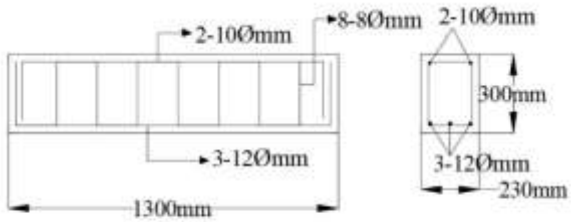

Figure 2: Reinforcement of beam details

Figure 3 shows the casted beam with 10mm diameter reinforced steel bars.

Figure 3: Casted beam

IV. RESULTS AND DISCUSSIONS

A. Compressive strength

The compressive strength of concrete with Ordinary Portland cement, silica fume and GGBS concrete at the age of 7days and 28days are conducted. The maximum 28days cube compressive strength of M60 grade with replacement in combination of 20% GGBS and 6% silica fume was 78MPa. Table IV is Compressive strength results of Plain concrete for M60.

Table IV: Compressive strength of Plain concrete

Mix Id	7 days	28 days
100C0S0G	43.55 N/mm²	65.33 N/mm²

Figure 4 show the compressive strength of Plain concrete for M60.

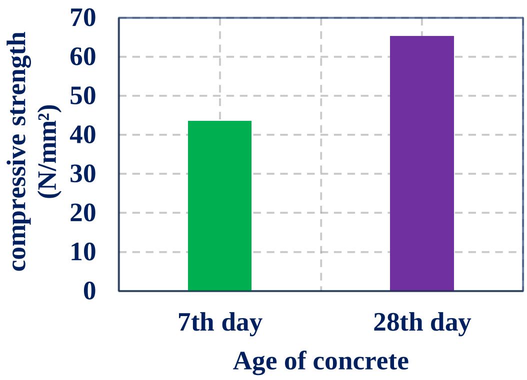

Figure 4: Compressive strength of concrete.

Table V shows the Compressive strength of concrete for partial replacement of GGBS and constant add 2% of Silica fume for M60.

Table V: Compressive strength of concrete

Mix Id	7 days	28 days
90C2S10G	56.66 N/mm²	64.88 N/mm²
80C2S20G	58.22 N/mm²	72 N/mm²
70C2S30G	59.55 N/mm²	69.33 N/mm²
60C2S40G	58.66 N/mm²	64.44 N/mm²

Figure 5 show the Compressive strength of concrete for partial replacement of GGBS and constant 2% of silica fume for M60.

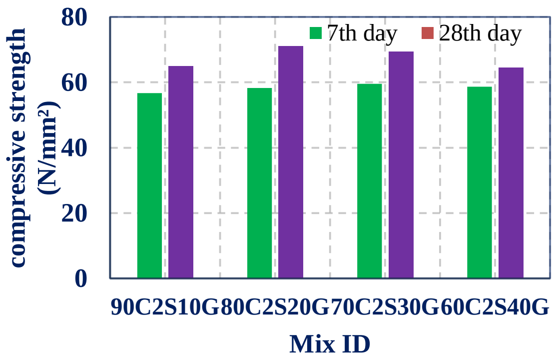

Figure 5: 2% Silica fume for M60

Table VI show the Compressive strength of concrete for partial replacement of GGBS and constant 4% of silica fume for M60.

Table VI: Compressive strength of concrete

Mix Id	7 days	28 days
90C4S10G	57.33 N/mm²	66.66 N/mm²
80C4S20G	60.88 N/mm²	73.33 N/mm²
70C4S30G	60 N/mm²	70.22 N/mm²
60C4S40G	59.55 N/mm²	62.22 N/mm²

Figure 0.04"6 show the Compressive strength of

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concrete for partial replacement of GGBS and constant 4% of silica fume for M60

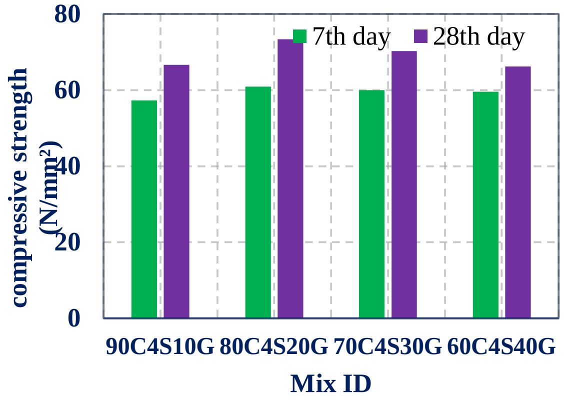

Figure 6: 4% of silica fume for M60

Table VII show the Compressive strength of concrete for partial replacement of GGBS and constant 6% of silica fume for M60.

Table VII: Compressive strength of concrete

Mix Id	7 days	28 days
90C6S10G	58.22 N/mm²	71.11 N/mm²
80C6S20G	62.88 N/mm²	78.44 N/mm²
70C6S30G	61.77 N/mm²	72 N/mm²
60C6S40G	60.44 N/mm²	68.44 N/mm²

Figure 7 show the Compressive strength of concrete for partial replacement of GGBS and constant 4% of silica fume for M60

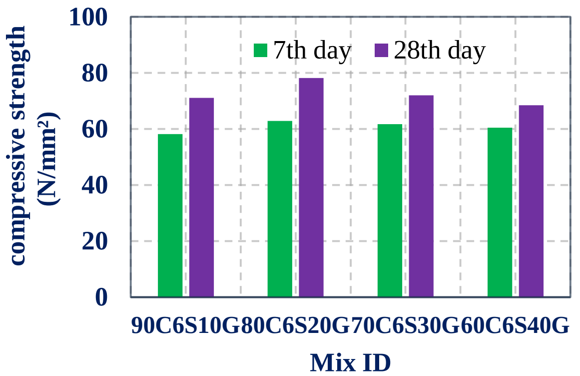

Figure7: 6% of silica fume for M60

B. Split tensile strength

The Split tensile strength test was carried out conforming to IS 5816:1999 to obtained split tensile strength for M60 grade of concrete. The split tensile strength of concrete with GGBS and silica fume at the age of 7days, 28days are conducted. The maximum 28days cylinder split tensile strength of M60 grade with replacement in combination of 20% GGBS and 6% silica fume was 5.3MPa. Table VIII is show Split tensile strength of Plain concrete results for M60.

Table VIII: Split tensile strength of concrete

Mix Id	7 days	28 days
100C0S0G	4.24 N/mm²	4.5 N/mm²

Figure 8 shows the Split tensile strength of Plain concrete for M60 in a bar chart representation for 7 and 28 days.

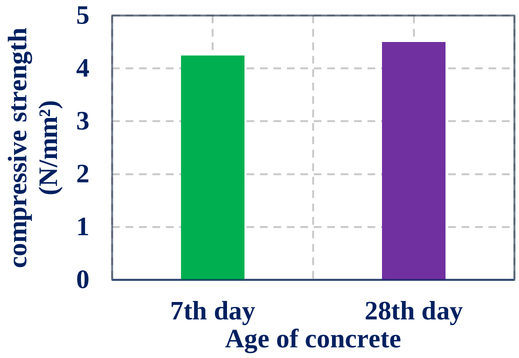

Figure 8: Split tensile strength of Plain concrete

Table IX shows the Split tensile strength of concrete for Partial replacement of GGBS and constant 2% of silica fume for M60

Table IX: Split tensile strength of concrete

Mix Id	7 days	28 days
90C2S10G	3.39N/mm²	3.748 N/mm²
80C2S20G	3.9 N/mm²	4.38 N/mm²
70C2S30G	4.102 N/mm²	4.3147 N/mm²
60C2S40G	3.678 N/mm²	4.244 N/mm²

Figure 9 show the Split tensile strength of concrete for different percentages of GGBS and constant 2% of silica fume for M60.

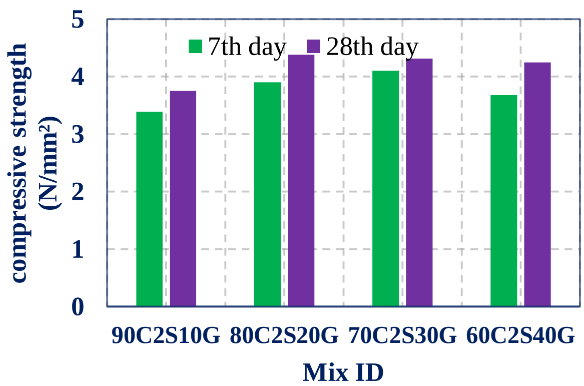

Figure 9: 2% of silica fume for M60

Table X show the Split tensile strength of concrete for different percentages of GGBS and constant 4% of silica fume for M60.

Table X: Split tensile strength of concrete

Mix Id	7 days	28 days
90C4S10G	4.66 N/mm²	5.092 N/mm²
80C4S20G	4.52 N/mm²	4.732 N/mm²
70C4S30G	4.224 N/mm²	4.52 N/mm²
60C4S40G	4.102 N/mm²	4.662 N/mm²

Figure 10 show the Split tensile strength of concrete for different percentages of GGBS and constant 4% of silica fume for M60.

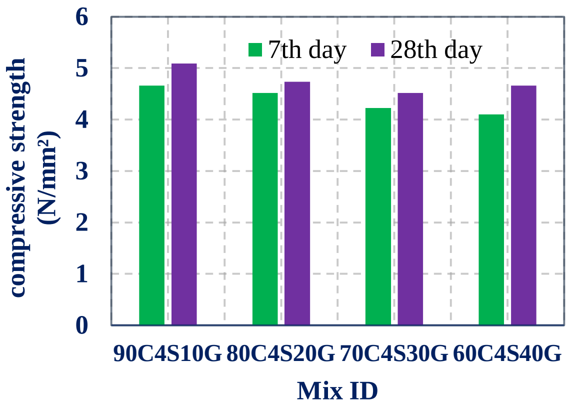

Figure 10: 4% of silica fume for M60

Table XI show the Split tensile strength of concrete for different percentages of GGBS and constant 6% of silica fume for M60

Table XI: Split tensile strength of concrete

Mix Id	7 days	28 days
90C6S10G	4.66 N/mm²	5.163 N/mm²
80C6S20G	4.95 N/mm²	5.3 N/mm²
70C6S30G	4.385 N/mm²	4.95 N/mm²
60C6S40G	4.244 N/mm²	4.81 N/mm²

Figure 11 show the Split tensile strength of concrete for different percentages of GGBS and constant 6% of silica fume for M60.

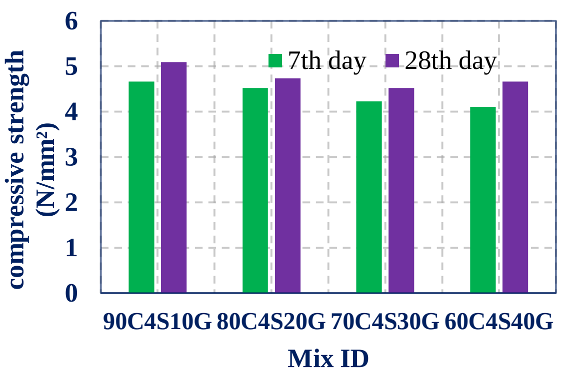

Figure 11: 6% of silica fume for M60

C. Testing

After the curing time, the beam specimens were cleaned to remove dirt. Then whitewashed (Birla white) were applied to facilitate easy detection of cracks. The beam specimens were tested under loading frame having a capacity of 1500 kN and hydraulic jack of 500 kN capacity subjected to 1-point, 2- point and UD Loadings. After the initial crack load the load increases. The initial crack load and deflection at the initial crack load, ultimate load and deflection at ultimate load were noted and the crack pattern was marked on the beam.

D. Failure Mode and Crack Pattern

Beyond the peak load, the no. of cracks stabilized and the cracks at the mid span. At failure load, the beams deflected significantly. The failure pattern of the beam specimens was found to be similar for the High performance reinforced concrete beams. The failure in all cases was initiated by yielding of the tensile steel followed by the crushing of concrete in the compressive face. Figure 12 shows the crack pattern of 1-point loading beam with average ultimate load is 165kN and crack width is 2mm.

Figure 12: 1-point loading

Figure 13 show the load-deflection curve obtained for 1-point loading beam.

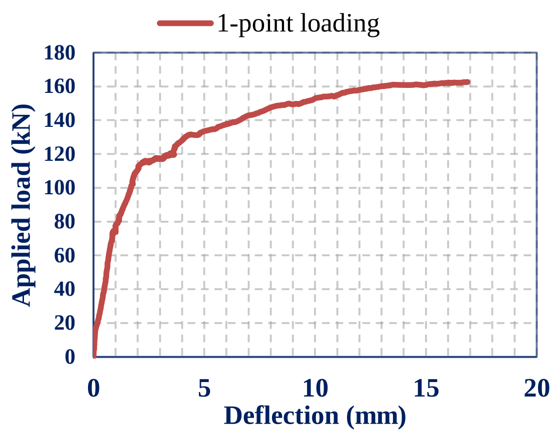

Figure 13: Load-deflection curve

Figure 14 shows the crack pattern of 2-point loading beam with average ultimate load is 320kN and crack width is 1.2mm.

Figure 14: 2-point loading

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Figure 15 shows the load-deflection curve obtained for 2-point loading beam.

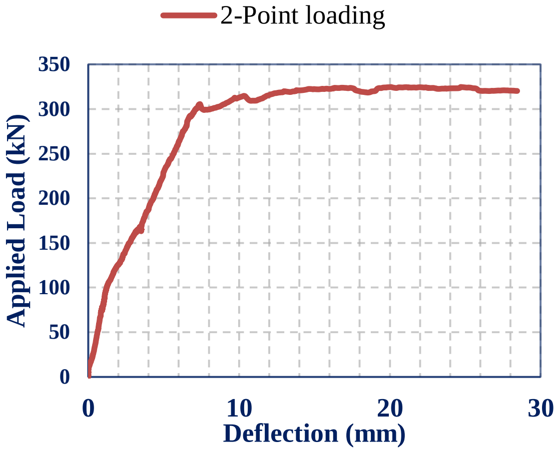

Figure15: Load-Deflection Curve

Figure 16 shows the crack pattern of uniformly distribution loading beam with average ultimate load is 165kN and crack width is 1mm.

Figure 16: Uniformly distribution loading

Figure 17 shows the load-deflection curve obtained for uniformly distribution loading beam.

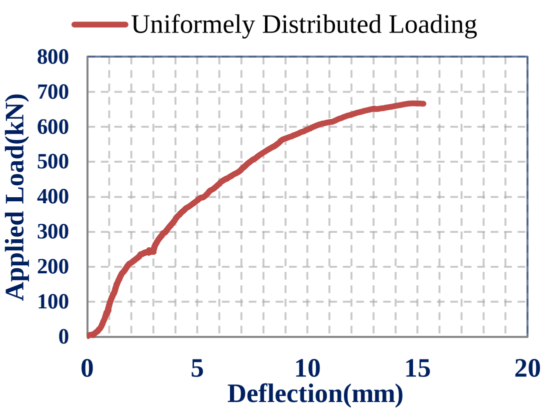

Figure 17: Load-deflection curve

V. CONCLUSION

Based on experimental investigations the following conclusions were made are:

1. M60 mix design procedure for HPC using SF and super plasticizer is formulated by ACI methods of mix design and available literatures on HPC.
2. It was observed that at 28 days, compressive strength of M60 grade of concrete increased by 20% in strength and split tensile strength was increased by 17.77% of strength for combination of 20% GGBS and adding 6% silica fume as admixture when compared to that of controlled concrete.
3. Beyond 30 to 40% replacement of GGBS, compressive strength and split tensile were decreased.
4. There was a decrease in workability (slump) as the replacement level increase.
5. The addition of silica fume is improving the bond strength of concrete and decreasing the permeability of concrete.
6. The compression (cube) failure pattern of concrete is due to crushing of coarse aggregates and not due to bond failure.
7. From the test results of cubes and cylinders, the percentage of water absorption of the HPC mixes containing silica fume was lower, when compared to controlled mixes (without silica fume).
8. By taking three types of loading conditions, such as 1-point, 2-point and uniform distribution loadings. The flexural behavior of the High-performance concrete can be analysis from the observation of 1- point load consists of flexural crack pattern. Similarly, 2-point and uniformly distributed load will get the flexural crack pattern and true shear.

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