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Flexural Behaviour of Reinforced High Performance Concrete Beams with Manufactured Sand and Silica Fume

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ABSTRACT
High Performance Concrete (HPC) is defined as a concrete that meets special performance and uniformity requirements that can not always be achieved routinely by using conventional materials and normal mixing, placing and curing practices. Most application of HPC has been in tall buildings, bridges and offshore structures. An experimental investigation was carried out to understand the structural behavior of reinforced concrete HPC beams of size 1800mm (length) x 150mm (width) x 200mm (depth).The ordinary Portland cement was partially replaced with silica fume by 5%, 10% and 12.5%. The natural sand was completely replaced with Manufactured Sand (M-Sand) with all percentage of silica fume replacement. The concrete used in this investigation was proportioned to target a mean strength of 60 MPa and designed as per ACI 211.4R-08.This paper presents the load deflection characteristics of HPC concrete made with silica fume and M-Sand compared with conventional concrete mix. Maximum ultimate load carrying capacity and the least deflection is obtained for the mix prepared by partial replacement of cement with 10% silicafume & natural sand by 100% M-Sand.The mineral fillers in M- Sand and silica fume increased the flexural stiffness of HPC beam. The test results showed that it is possible to produce HPC using M-Sand with silica fume.

Keywords
High-performance concrete, M-Sand, Deflection, Silica fume, reinforced concrete.

1. INTRODUCTION
Globally many countries are witnessing a rapid growth in the construction industry which involves the use of natural resources for the development of the infrastructure. In general, the demand of natural sand is quite high in developing countries to satisfy the infrastructural growth, in these situation developing countries like India is facing shortage in good quality natural sand [1, 2]. On the otherhand the cement plays a vital role in the construction industry, worldwide the production of cement is increasing at a faster rate, nearly 3,300 million tones of cement has been produced during last year. The amount of CO_2 emitted by a cement industry is nearly 900 kg of CO_2 for every 1000 kg of cement produced, a major contributor for green house effect and global warming[3,4]. In order to compensate the lack of natural resources and to find alternative solution for conserving the environment, and to make the construction industry sustainable, the natural sand was replaced by Manufactured Sand (M-Sand) and silica fume as replacement of cement for making concrete. Silica fume is a by product resulting from the manufacture of silicon and ferrosilicon alloys. Compared with other supplementary cementitious materials the peculiar characteristics that make silica fume a very reactive pozzolona are its high SiO_2 content, its amorphous state and its extreme fineness improves strength and durability properties [5, 6]. Researchers found that at 5-15% replacement of cement by silica fume with a smaller dosage of super plasticizer improve the workability and strength of concrete [7-9]. M-Sand is a crushed aggregate produced from hard granite stone which is rough, flaky shaped with sharp edges, washed and graded with consistency to be used as a substitute of river sand. The mechanical and durability properties of concrete incorporating M-sand are enhanced due to its filler content and interlocking effect between the particles. [10- 13]. On the contrary, the angular shape of the M-Sand particles tends to reduce the workability which can be improved by the use of water reducers and mineral admixtures.[14, 15] In this research both the materials silica fume and M – Sand are combined replacement for cement and natural sand. Taking into consideration of the above mentioned points, this research work poses to use the manufactured sand as a complete replacement of natural. The cement was replaced by 5%, 10% and 15% of silica fume with the addition of superplasticizer equal to 1.5% by weight of binder(cement & silica fume).Further, the study helps to identify an alternate material for natural sand and to minimize the usage

of cement content to some proportion in the High Performance Concrete.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Cement

Ordinary Portland cement of 53 Grade was used and the specific gravity of cement was found to be 3.15. The physical and chemical properties of cement are presented in Table 1.

2.1.2 Silica Fume:

Silica fume was collected from ELKEN South Asia Pvt.Ltd. Mumbai, was named Elkem – Micro silica 920 D conforming to ASTM C1240(1998)[16]. It is available in dry densified form. The physical and chemical properties of cement and silica fume are also presented in Table 1.

Table 1. Physical and Chemical Properties of Cement & Silica fume

Properties	Cement	Silica fume
Physical Properties		
Specific gravity	3.15	2.2
Surface area, m^2/kg	320	20,000
Size, micron	-	0.1
Bulk density, kg/m	-	576
Initial setting Time (min)	45	-
Final setting Time(min)	375	-
Chemical Properties, Percentage		
SiO_2	90-96	20-25
Al_2O_3	0.5-0.8	4-8
MgO	0.5-1.5	0.1-3
Fe_2O_3	0.2-0.8	0.5-0.6
CaO	0.1-0.5	60-65
Na_2O	0.2-0.7	0.1-0.5
K_2O	0.4-1	0.4-1.3
Loss of Ignition	0.7-2.5	0.1-7.5

2.1.3 Fine Aggregates

Locally available river sand having bulk density 1726 kg/m^3 was used and the specific gravity is 2.65. The Fineness modulus of river sand is 2.69.

2.1.4 Manufactured Sand

M- Sand was used as partial replacement of fine aggregate. It was collected from I Blue Minerals Pvt. Ltd. Karur, India. The bulk density of manufactured sand was 1748 kg/m^3, specific gravity and fineness modulus was found to be 2.65 and 2.86 respectively. The percentage of particles passing through various sieve were compared with natural sand and it was found to be similar. The results are presented in Table.2.

Table 2. Details of sieve analysis for natural sand and M-sand

Sieve Size	Natural sand % Passing	M-Sand % Passing	IS Grading limits for Zone II
4.75mm	97	99.2	90-100
2.36mm	92.2	93.6	75-100
1.18mm	77	56.6	55-90
600µm	52.2	38.6	35-59
300 µm	10.6	18.4	8-30
150 µm	2	7.4	0-10
	Conforming to grading Zone II of IS 383		-

2.1.5 Coarse Aggregate

Locally available crushed coarse aggregate having maximum size 12.5 mm was used. It was confirming as per Indian standard (IS- 383-1970)[17] and satisfied its requirement. Coarse aggregate passing through 12.5 mm sieve was 90–100%. Passing through 10 mm sieve was 40–80% and passing through 4.75 mm sieve was 0–10%. The specific gravity of coarse aggregate is 2.71.

2.1.6 Super plasticizer

In order to improve the workability of high-performance concrete, super plasticizer in the form of poly-carboxylic ether based superplasticizer (Glenium B233) was used as chemical admixture. The product has specific gravity of 1.09 and solid contents not less than 30% by weight.

2.1.7 Water

Fresh portable water, which is free from acid and organic substance, was used for mixing the concrete.

2.2 Methods

2.2.1 Mix design and sample preparation

Concrete mix design in this investigation was designed as per the guidelines specified in ACI 211.4R-08 - “Guide for selecting proportions for high strength concrete with portland cement and other cementations materials”. The mix proportions used in this investigation is 1: 1.1: 2.08: 0.32. The detailed mix proportions are presented in Table 3.

Table 3. Mix proportion for High Performance Concrete

Material (kg/m^3)	Mix Designation				
	M1	M2	M3	M4	M5
Cement	551.87	551.87	524.27	510.47	482.87
Silica Fume	0	0	27.6 (5%)	41.4 (10%)	69 (12.5%)
Natural Sand	672	0	0	0	0
M-Sand	0	672	672	672	672
Coarse aggregate	1149.8	1149.8	1149.8	1149.8	1149.8
Water	162.1	162.1	162.1	162.1	162.1
Super Plasticizer	8.0	8.0	8.0	8.0	8.0

Typical reinforcement arrangement and geometry of the beam are shown in Fig. 1.

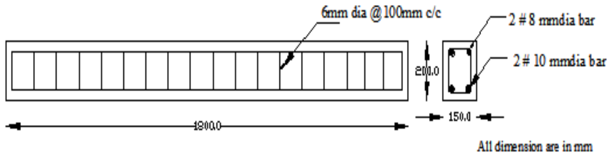

Figure 1. Reinforcement Details

All the beams were cast in wooden moulds and the concrete specimens cube and prisms were cast in standard steel moulds. For each mix, three numbers of 100mm cubes for compressive strength, three numbers of 100mm x 100mm x 500mm prisms for flexural strength were cast. The quantities of cement, fine aggregate, coarse aggregate, silica fume, M-Sand for each proportion is measured and homogeneous mixing of the above is achieved by means of pan mixer. The water to binder ratio was kept as 0.32 and the dosage of super plasticizer was kept constant at 1.5% by weight of binder (Cement + Silica fume) to get the workability of concrete. The concrete was thoroughly mixed until it achieved homogeneous and uniform consistency. The fresh concrete was casted and it was compacted by needle vibrator. All freshly cast specimens were left in the moulds for 24 hours before being de moulded. The beams were demoulded after 24 h and were cured with water for 28 days.

2.2.2 Testing of Specimens

Compressive strength test was conducted at the age of 28-day accordance with IS 1881: Part 116 [18] using a loading rate of 140 kg/cm^2 per minute till the specimens fails. Test was conducted using AIMIL Compression Testing Machine (CTM) of capacity 2000KN. Flexural strength of concrete was carried out conforming to IS: 516-1959 [19], prisms were tested using Flexure Testing Machine (FTM) of capacity 100KN. All the reinforced beam specimens were tested in a self-straining loading frame of capacity 2000 kN and load cell of 10 ton. The specimen was placed in position and simply supported boundary conditions were made. The effective span was kept 1600mm. The specimens were tested under two point loading. Two rollers served as load point and were kept on the beams at a distance of 530mm. The load was applied in increments. The deflection at mid span was measured using deflectometer for every increment of load. Load was measured using proving ring. Load at the formation of first crack and ultimate load were noted.

3. RESULTS AND DISCUSSIONS

3.1 Compressive Strength& Flexural Strength

The results of compressive strength and flexural strength of concrete at the age of 28 days are shown in the Table.4. It shows the variation of compressive strength with 5%, 7.5 % and 12.5% replacement of cement by silica fume and natural sand by 100% M-Sand.

Table 4. Compressive and Flexural strength of HPC at 28 days

Mix Details	Compressive Strength in N/mm^2	Flexural strength in N/mm^2
M1	62.27	5.17
M2	67.56	6.45
M3	75.78	7.16
M4	80.11	9.24
M5	65.67	5.42

It could be observed that a concrete mixture made with 100% manufactured sand shows higher compressive strength than control concrete at all replacements of silica fume. From the results, 28days compressive strength increased by 8.13%, 18.21%, 23%, 5% for the mix M-2, M-3, M-4&M-5 respectively than control mix M-1. The compressive strength of concrete with 100% M-Sand and 5%, 10% silica fume mix was increased gradually up to an optimum replacement level of 10% and then decreased for 12.5% of silica fume. There is a significant improvement in the compressive strength of concrete because of the high pozzolanic nature of the silica fume. Due to void filling ability and also the sharp edges of the particles in manufactured sand provide better bond with cement than the rounded particles of natural sand resulting in higher strength. The same pattern was observed in the flexure strength of concrete.

3.2 Structural behavior of beam

Comparison of load verses deflection curves was presented in Fig.2 to 5.

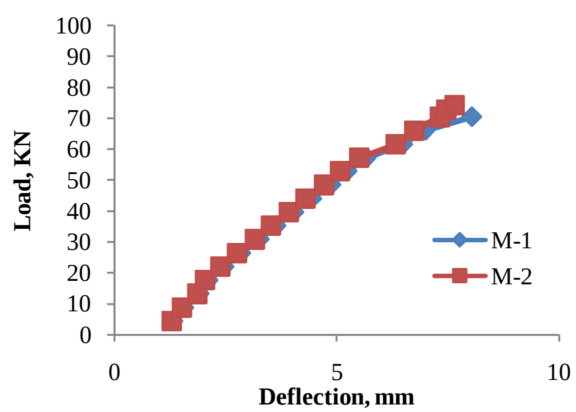

Figure 2. Comparison of deflection between M-1 and M-2 beams

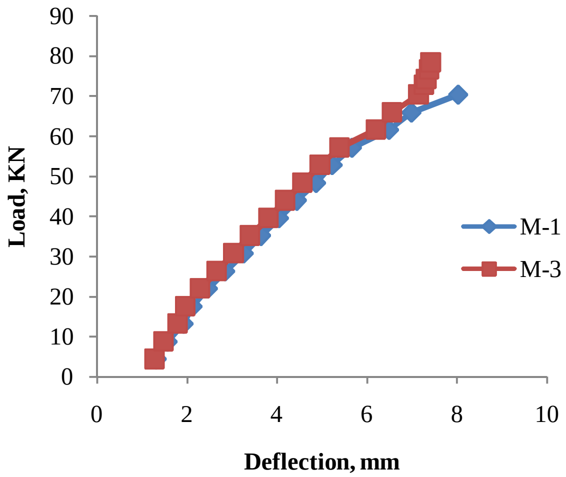

Figure 3. Comparison of deflection between M-1 and M-3 beams

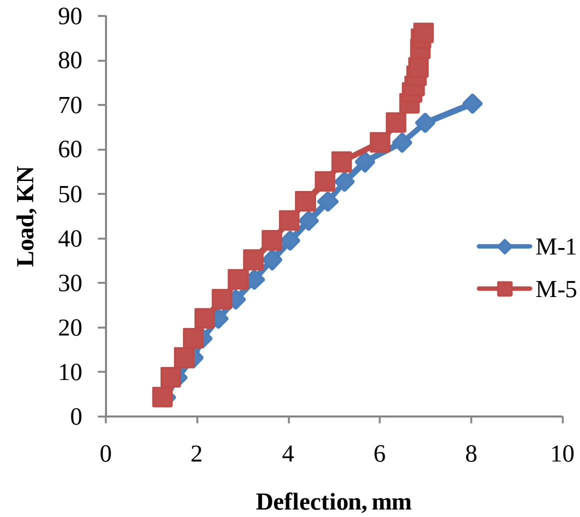

Figure 5. Comparison of deflection between M-1 and M-5 beams

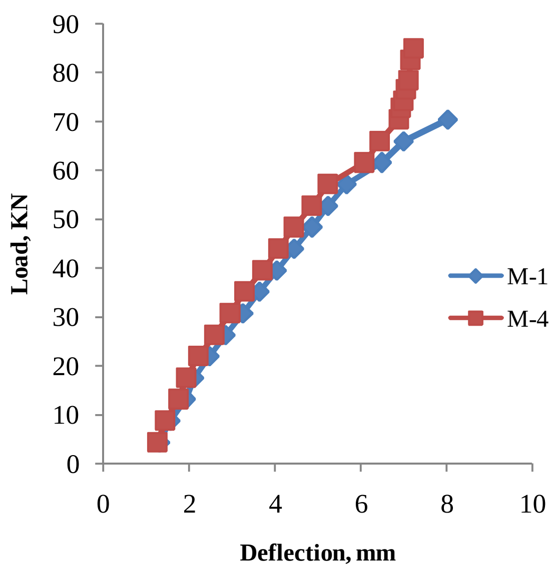

Figure 4. Comparison of deflection between M-1 and M-4 beams

a)Crack pattern for control mix M1

b) Crack pattern for Mix M4

Figure 6. Crack pattern

Table 5 presents the details of first crack load and ultimate load and corresponding deflections.

Table 5. Details of crack initiation load, ultimate load and corresponding deflection

Beam ID	Visible first crack load, kN	Corresponding deflection, mm	Ultimate load, kN	Corresponding deflection, mm
M1	32.6	3.38	72.8	7.86
M2	34.5	3.42	74.2	7.46
M3	36.4	3.53	78.4	7.42
M4	37.3	3.57	86.2	6.96
M5	37.1	3.56	84.9	7.23

From Table 5, it can be noted that the deflection is increasing linearly with the load. It is noticed that for control concrete mix M1, the first crack appears at a load of 32.6 kN and it does not appear for the optimum concrete mix M4 until 37.3kN. The ultimate load carrying capacity of the control concrete mix M1 of 72.8kN. For all other mixes with 100% M-Sand, the ultimate load capacities were found to be 74.2kN, 78.4kN, 86.2kN and 84.9kN respectively for 0, 5, 10 and 12.5% of silica fume. The capacities of mixes M2, M3,M4 and M5 increased about 5, 12, 20 and 18% respectively when compared to the control HPC mix. From the above observations, it is seen that the ultimate load of the beam with manufactured sand increases with increase in silica fume content upto 10% replacement after which it decreases. For the combination of 100% replacement of fine aggregate by M-Sand and 10% replacement of cement by silica fume, the load carrying capacity is found to be very high compared to control beam (about 20%) and the corresponding deflections are found to be lesser. The above observations are supported by the work of other researchers who studied the influence of manufactured sand as fine aggregate on the normal strength concrete[20-22].

4. CONCLUSION

Based on the investigations, following conclusions can be made.

- The High Performance Concrete with M-Sand can be used as an alternative material to natural sand in the presence of silica fume.
- The compressive strength and flexural strength of concrete showed increase in 100% M-Sand and increase gradually as the percentage of silica fume increased upto 10% after which decreases the strength for further replacement level.
- The optimum percentage of natural sand replacement by 100% M-Sand in presence of replacement of cement by 10% of silica fume for achieving maximum compressive and flexural strength.
- The RC beams with M-Sand sustained more load under two point loading, and developed smaller deflections than the beams with river sand.
- The load carrying capacity is found to be 20% higher for the concrete made with 100% replacement of fine aggregate by M-Sand and 10% replacement of cement by silica fume compared to control beam.
- Based on the test results , it can be concluded that M-Sand can be adopted with presence of silica fume in High Performance Concrete.

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