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BEARING STRENGTH OF SILICA FUME CONCRETE WITH BEARING TO PUNCHING AREA RATIO OF 15

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Abstract: This document presents the bearing and compressive strengths of steel fibre reinforced silica fume concrete. To evaluate the strengths standard size cube specimens cast and tested in compression testing machine. Total six mixes were taken for this study, in the mixes the silica fume was used as partial replacement of cement with various proportions of 0, 5,10,15,20 and 25%. In all the mixes the crimpled steel fibres were also added with the dosage of 1 and 2% by volume of specimen. The obtained bearing strength results were compared with the existing codes of IS 456 and ACI 318 cods. Few regression models were deduced to assess the experimental results with precision. The results showed that, the mix with 15% silica fume is optimum and also observed that, the addition of steel fibres for all the mixes are effective to exhibit high bearing strength.

Key Words: Bearing strength, Area ratio 15, Compressive strength, Crimpled steel fibre, Silica fume, Regression models, IS and ACI codes.

1. General

The large scale consumption of raw materials by the construction sector results the shortage of building materials and this may scare the future generation. For this reason the civil engineers have been challenged to convert the industrial wastes to useful building and construction materials. Many research activities were directed to utilize the waste material into the construction industry with suitable technical support. For design aspect some researchers developed new methodologies for design of structural element with proper guidelines. The IS code suggested to use the mineral admixtures in order to save the cement consumption for the construction industry, the usage of less quantity of cement is also decreases the energy levels during manufacturing stage. Among many admixtures the flash, silica fume, risk husk ash, meta kaolin are few important admixtures. These admixtures may use in the cement concrete mix as partial replacement to cement and many past research works are there to evaluate the mechanical properties of the mixes. The research went to ahead to increase the strength of plane concrete strength with incorporation of natural and artificial fibres. Apart many fibres, steel fibres are occupied the first place in both strength and economic wise. The present work has been planned to evaluate the bearing strength of silica fume concrete with and without use of crimpled steel fibres. Before going in detail about the experimental work the resent past literature is presenting here in to know the status in this area or arena. Carson and Chen [1] studied the influence of adding steel fibres on the bearing capacity and ductility of concrete through testing 150mm concrete cylinders. It was found that the bearing capacity was significantly higher than that of unreinforced materials. Niyogi[2] conducted extensive investigation on the bearing strength of concrete. The variables investigated were the geometry of specimens, the bearing area, mix proportions, strength of concrete, amount and form of reinforcement and nature of the bed. Wee et al.[3] also showed that silica fume, at replacement levels of 5 and 10%by mass of OPC plays a key role in resisting sodium sulphate attack, indicating no signs of spalling after about 1 year of exposure in 5% sodium sulphate solution. Hekal et al.[4] reported that partial replacement of Portland cement by silica fume (10–15%) did not show a significant improvement in sulphate resistance of hardened cement pastes. Shannag and Shaia[5] prepared high-performance concrete mixes containing various proportions of natural pozzolan and silica fume (up to 15% by weight of cement). The results also showed that magnesium sulphates had a more damaging effect than sodium sulphates.Mazloom et al. [6] made high-performance concrete containing silica fume. The silica fume content was 0, 6, 10, and 15%, and water–cementitious ratio being0.35 and 100 ± 10 mm, respectively. Behnood and Ziari [7] designed concrete mixtures to evaluate the effect of silica fume on the compressive strength of the heated and unheated concrete specimens. González-Fonteboa and Martinez-Abella [8] studied the properties of concrete using recycled aggregates from Spanish demolition debris (RC mixes) and the impact of the addition of silica fume on the properties of recycled concrete. Kadri and Duval [9] investigated the influence of silica fume on the hydration heat of concrete. Portland cement was replaced by silica fume (10–30% by mass)in concrete with w/(c +sf) ratios varying between 0.25 and 0.45. Suksun horpibulsuk et.al.[10] investigated the performance of fully instrumented test wall reinforced with bearing reinforcement and suggested a method of designing BRE wall. You-Fu-Yang et. al [11] investigated behaviour of concrete filled double-skin tube (CFDST) subjected to local bearing forces. The results showed the CFDST specimens have a high bearing capacity and a good deformation resistant ability on subjecting to local bearing forces. The bearing capacities obtained are compared experimentally. Chao Hou et. al [12] studied behavior of circular concrete filled double skin tubes (CFDST) subjected to local bearing forces . A finite element analysis was conducted between full range behavior of CFDST & CFST under local bearing. Based on load- transfer mechanism analysis, simplified formulae for predicting the strength of CFDST under local bearing forces are presented. Reasonable agreement between the predicted and measured values is achieved. Ali. A.Sayadi et. al [13] took up galvanized steel strips as embedded components and foamed concrete as infill material to investigate the effectiveness of interlocking area and bearing area on bond behaviour. The result indicates increase in locking area results in higher tensile capacity along with greater displacement in initial stage. Based on experimental results equations were developed to analytically describe the bond slip behaviour, tensile capacity and bond strength. Omid sargazi and Ehsan seyedi Hosseininia [14] presented a study on bearing capacity of eccentrically loaded rough ring footings resting over cohesion less soil. Comparison between the results of numerical simulations with those of analytical solutions and experimental data indicates good agreement. Amir Hossein Arshian and Guido Morgenthal [15] concentrated to assess the ultimate load bearing capacity of laterally restrained RC slabs considering the contribution of compressive membrane action. The sensitivity studies, non-influential parameters are fixed at their mean values and probability of failure is estimated for investigated modelling strategies using full probabilistic approach. From the above review of literature it is observed that no work has been carried out on bearing strength of concrete using Steel Fibres and Silica fume as admixture. Hence, an attempt has been made in this investigation to study the behaviour of silica fume concrete. The scope of present investigation is to evaluate the compressive and bearing strength of concrete. The cement replacement by the silica fume is in the proportion of 0, 5, 10, 15, 20&25%. In addition to this mixes, few more mixes were prepared with Crimped Steel Fibres by volume 0, 1 & 2% in concrete. For all mixes cubes of standard size 150mmx150mmx150mm were cast and tested in the laboratory. In the present experimental work total 108 cubes were cast, out of all cubes, 54 cubes were used for bearing strength and remaining cubes were used for compressive strength testing. For each mix three cubes were cast and tested, the average value of result was taken as strength of the mix.

2. Objectives

a. The specific objectives of the present investigation are
b. To study the fresh concrete property of workability by compaction factor test
c. To evaluate the compressive and bearing strengths of concrete
d. Applicability of IS456- 2000 and ACI318M-11 code provisions to estimate the strengths
e. Developing of Regression Modals to estimate the strengths

3. Materials used

3.1 Cement: Ordinary Portland cement of 53 grade confirming to IS 8112-1989 standards was used to cast the specimens. The specific gravity of cement was noticed as 3.1.
3.2 Silica Fume: The silica fume was obtained from Navabarath Ferro Alloy Plant at Palvancha of Badhardri kottagudem (Dist) in Telangana (state), India (country).The specific gravity for silica fume was noticed as 2.1 and the silica content was 89%
3.3 Fine aggregate: River sand from local sources was used as fine aggregate. The specific gravity of sand is observed as 2.58 and it was conformed to zone II based on sieve analysis.
3.4 Natural Coarse Aggregate: Crushed natural granite aggregate from local crusher has been used and which has maximum size of 20mm .The specific gravity of coarse aggregate was observed as 2.66.
3.5 Water: Clean fresh water was used for mixing and curing the specimens.
3.6 Fibres: Steel Fibres are supplied by “Stewols India (P) Ltd, an ISO 9001: 2008 Company” at Nagpur. The most important parameter describing a fibre is its Aspect ratio. "Aspect ratio" is the length of fibre divided by an equivalent diameter of the fibre, where equivalent diameter is the diameter of the circle with an area equal to the cross sectional area of fibre. In the present investigation crimped round fibres were used with aspect ratio of 90 and the physical properties are presented Table 1 and the used fibres can viewed in Figure 1.

Fig.1: Crimped steel fibre

Table 1: Details of Crimple fibre

Length of Fiber	50.00 mm
Aspect ratio	90.00
Diameter (d)	0.55 mm
Width (w)	2.5 mm
Tensile Strength	450Mpa
Physical form	Clear, bright and undulated along the length
Material Type	Low Carbon Drawn Flat Wire

4. Casting

The cubes were cast in steel moulds with inner dimensions of 150 x 150 x 150mm.The cement, silica fume; sand, coarse aggregate and crimped steel fibres were mixed thoroughly manually. The mix proportion was adopted for all mixes as 1:1.63:3.12 and water cement ration was arrived as 0.5. (This was designed for M20 grade concrete) During mixing of concrete initially 25% of water required is added and mixed thoroughly till to obtain uniform mix. After that, the balance of 75% of water was added and mixed thoroughly with a view to obtain design mix. Care has to be taken in mixing to avoid balling effect.For all test specimens, moulds were kept on table vibrator and the concrete was poured into the moulds in three layers and compaction was provided with tamping rod, in addition to this table vibrator was also provided.The moulds were removed after twenty four hours and the specimens were deployed to curing pond. After curing the specimens in water for a period of 28 days the specimens were taken out and allow drying under shade.

5. Testing

5.1 Compaction factor test

The compaction factor test apparatus consists of two hoppers, each in the shape of frustum of a cone and one cylinder. The upper hopper is filled with concrete this being placed gently so that no work is done on the concrete at this stage to produce compaction. The second hopper is smaller than the upper one and is therefore filled to overflowing. The concrete is allowed to fall in to the lower hopper by opening the trap door and then into the cylindrical mould placed at the bottom. Excess concrete across the top of the cylindrical mould is cut and the net weight of the concrete in cylinder is determined. This gives the weight of partially compacted concrete. Then the cylindrical mould is filled with concrete in layers of 5cm depth by compacting each layer fully. The fully compacted weight is then determined and compaction factor (C.F) is calculated by using the stand formula.

5.2 Compressive strength test

Compression test on cubes is conducted with 2000kN capacity of compression testing machine. The machine has a least count of 1kN. The cube was placed in the compression-testing machine and the load on the cube is applied at a constant rate till to failure of the specimen and the corresponding load is noted as ultimate load. Then cube compressive strength of the concrete mix is then computed by using standard formula and the obtained values are presented in the next section.

5.3 Bearing Strength test

The bearing strength test was conducted on cubes. To analogous the column and footing, a steel plate 38.70mm (breadth) x 38.70mm (width) x 25mm (thick) was placed on cubes and tested in cube compression machine. The size of the square plate (38.70x38.70mm) is prepared so as to achive the bearing area to the punching area is 15. A 2000 KN Compression testing machine was used for testing and the axial load is applied at a constant rate as laid down in IS: 516-1959. The obtained test resulted presented in the next section.

6. Discussion of Test Results

6.1 Workability

The workability of mixes has been measured by Compaction factor test. The values of compaction factors results are presented in Table 2. From this it is observed that the compaction factor decrease with increase in the % of Silica fume in the concrete mix. This type of observations were made by Swami B.L.P et.al.[16] and V.Bhikshma et.al.[17] The results indicates that as the silica fume content increases in the mixes the compaction factor decreases which may be due to high specific surface of silica fume.

Table 2: Workability

S .No	Nomenclature	Compaction Factor(CF) 0% fibre	Compaction Factor(CF) 1% fibre	Compaction Factor(CF) 2% fibre
1.	NC	0.915	0.898	0.871
2.	SF5	0.892	0.874	0.862
3.	SF10	0.858	0.837	0.822
4.	SF15	0.834	0.821	0.806
5.	SF20	0.816	0.792	0.775
6.	SF25	0.796	0.781	0.762

6.2 Compressive Strength

6.2.1 First crack (FC) stage

The compressive strengths for all mixes (for various replacements0, 5, 10, 15, 20&25%) with 0%, 1% &2% fiber are presented in Table 3. From this, it can be observed that for 0% fiber the 28 days compressive strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube compressive strength by 24.07% over NC. For 25% replacement level, the compressive strength has decrease by 9.24% when compared with reference concrete. Verma Ajay et.al.[18] has been presented in their experimental work as 15% silica fume is optimum. For 1% fiber the 28 days compressive strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube compressive strength by 21.06% over NC. For 25% replacement level, the compressive strength has decrease by 5.22% when compared with reference concrete. For 2% fiber the 28 days compressive strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube compressive strength by 17.16% over NC. For 25% replacement level, the compressive strength has decrease by 12.76% when compared with reference concrete or NC.

Table 3: Compressive strength at first crack

S .No	Nomenclature	Compressive strength(N/mm^2) 0% fibre	Compressive strength(N/mm^2) 1% fibre	Compressive strength(N/mm^2) 2% fibre

1.	NC	23.68	24.68	26.39
2.	SF5	25.00	26.18	26.57
3.	SF10	27.96	28.34	29.19
4.	SF15	29.38	29.88	30.92
5.	SF20	24.62	25.35	25.60
6.	SF25	21.49	23.39	23.02

6.2.2 Ultimate stage (US)

The compressive strengths for all mixes (for various replacements 0, 5,10,15,20 &25%) with 0%,1% &2% fiber are presented in Table 4. From those, it can be observed that for 0% fiber the 28 days compressive strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube compressive strength by 23.39% over NC. For 25% replacement level, the compressive strength has decrease by 9.81% when compared with reference concrete. But Swamy BLP et al [16], K.Perumal and R.Sundararajan [19] have reported in their investigation as 10% is optimum. But in the present experimental investigation 15% is found to be optimum. The presence of micro silica fume in the concrete mass is decrease the voids (the final product makes as denser and it leads higher strength carrying capacity) and also the silica fume may participate in chemical reaction with calcium hydroxide, it may results formation of CSH gel and leads to enhancement of strength . For 1% fiber the 28 days compressive strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube compressive strength by 21.04% over OPC. For 25% replacement level, the compressive strength has decrease by 9.68% when compared with reference concrete. For 2% fiber the 28 days compressive strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube compressive strength by 22.31% over OPC. For 25% replacement level, the compressive strength has decrease by 11.01% when compared with reference concrete or NC. Pu-Woei et.al.[20] has been presented in their experimental work as the percentage of carbon fiber increases in the mix the strengths were increases. Same types of observations were made in the present experimental work for steel fibers. Based on the rule of mixture the strengths were increased.

Table 4: Compressive strength values at ultimate stage

S.No	Nomenclature	Compressive strength(N/mm^2) 0% fibre	Compressive strength(N/mm^2) 1% fibre	Compressive strength(N/mm^2) 2% fibre
1.	NC	32.61	33.97	35.13
2.	SF5	34.26	35.38	36.82
3.	SF10	37.79	39.02	40.19
4.	SF15	40.24	41.12	42.97
5.	SF20	33.86	34.92	35.71
6.	SF25	29.41	30.68	31.26

6.3 Influence of Silica Fume on Bearing Strength

The allowable bearing stress depends on the bearing strength of concrete and this often controls the dimensions of the members. According to ACI 318 the ultimate stress under concentrated forces is called bearing strength. In reality this type of forces are encountered in the area of missiles, projectiles and explosions

(S.P Ray and B.Venkateswarulu [21]). In the present experimental work the author is focused the bearing strength evaluation for pedestal purpose only.

6.4 Bearing strength

6.4.1 First crack (FC) stage

The bearing strengths for all mixes (for various replacements of 0, 5,10,15,20 &25%) with 0%, 1% &2% fiber are presented in Table 5. From this, it can be observed that for 0% fiber, the 28 days bearing strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube bearing strength by 40.64% over NC. For 25% replacement level, the bearing strength has decreased by 12.75% when compared with reference concrete. For 1% fiber the 28 days bearing strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube bearing strength by 38.30% over NC. For 25% replacement level, the bearing strength has decreased by 10.09% when compared with reference concrete. For 2% fiber the 28 days bearing strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube bearing strength by 36.89% over NC. For 25% replacement level, the bearing strength has decreased by 9.57% when compared with reference concrete

Table 5: Bearing strength at first crack

Sl. No	Nomenclature	Bearing strength(N/mm^2) 0% fibre	Bearing strength(N/mm^2) 1% fibre	Bearing strength(N/mm^2) 2% fibre
1.	NC	96.69	101.05	106.29
2.	SF5	106.99	109.74	116.02
3.	SF10	125.79	130.25	133.78
4.	SF15	135.99	139.76	145.51
5.	SF20	105.63	110.02	114.24
6.	SF25	84.36	89.94	96.11

6.4.2 Ultimate stage (US)

The bearing strengths for all mixes (for various replacements of 0, 5,10,15,20 &25%) with 0%, 1% &2% fiber are presented in Table 6. From this, it can be observed that for 0% fiber the 28 days bearing strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube bearing strength by 40.05% over NC. For 25% replacement level, the bearing strength has decreased by 15.09% when compared with reference concrete. For 1% fiber the 28 days bearing strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube bearing strength by 37.48% over NC. For 25% replacement level, the bearing strength has decreased by 13.47% when compared with reference concrete. For 2% fiber the 28 days bearing strength increases with the increase in the percentage of silica fume up to 15%. For 15% replacement of silica fume there is increases in cube bearing strength by 36.15% over NC. For 25% replacement level, the bearing strength has decreased by 12.06% when compared with reference concrete.

Table 6: Bearing strength at ultimate stage

S. No	Nomenclature	Bearing strength(N/mm^2) 0% fibre	Bearing strength(N/mm^2) 1% fibre	Bearing strength(N/mm^2) 2% fibre
1.	NC	134.90	141.10	148.39
2.	SF5	147.99	151.84	160.43
3.	SF10	172.26	178.28	183.06
4.	SF15	188.94	193.99	202.04
5.	SF20	145.22	151.48	157.34
6.	SF25	114.47	122.09	130.49

6.5 Relationship between bearing and compressive strength

The bearing strength of concrete is most important parameter during the design of axially loaded elements. For normal concrete the IS 456-2000 and ACI 318M-11 recommended the following equations.
$f_f=0.45(f_{ck})\sqrt{(A1/A2)}$-------------------------IS 456-2000
$f_f=0.85øf_c^1$------------------------------------ ACI318M-11
f_{ck} = Characteristic compressive strength (N/mm^2),
f_c^1 = Specified compressive strength (N/mm^2) (for this work, it was taken as cube compressive strength)
ø = Strength reduction factor (taken as one unit)
The validity of the above equations was demonstrated in Table 7. From this table it is observed that the IS and ACI codes are underestimate the strengths. Hence the author is felt that there is a necessity to develop a regression model (RM) to suit the experimental values. The author developed a regression modal with a correlation coefficient R^2=0.99 for all % of fibres.
fb=2.036fck-0.15(%rep)+1.712--------------- for 0% fibre
fb=2.417fck-0.038(%rep)-10.44----------------for 1% fibre
fb=1.761fck-0.235(%rep)+16.77---------------for 2% fibre
In the above expressions
f_b = Bearing strength (N/mm^2),
f_{ck} = Characteristic compressive strength (N/mm^2),
% rep=Percentage of replacement
The performance of the proposed model is presented in Table 8. From this table, it is observed that, the ratio between EXP and RM is about 0.98 to 1.00. The ratio inferences the proposed model is best suited to the experimental values and also may concluded that it is better than IS and ACI code formulas

Table 7: Applicability of IS456-2000 and ACI318M-11 Codes

% Fibre	% SF	IS456-2000 (N/mm^2)	ACI 318-11 (N/mm^2)	Exp	Exp/ACI318M-11	Exp/IS456-2000
0%	0	29.35	22.17	134.90	4.59	6.08
	5	30.83	23.29	147.99	4.80	6.35
	10	34.01	26.01	172.26	5.06	6.62
	15	36.21	27.36	188.94	5.21	6.90
	20	30.47	23.02	145.22	4.76	6.30
	25	26.46	17.99	114.47	4.32	6.36
1%	0	30.57	23.09	141.10	4.61	6.11
	5	31.84	24.05	151.84	4.76	6.31
	10	35.11	26.53	178.28	5.07	6.71

	15	37.00	27.96	193.99	5.24	6.93
	20	31.42	23.74	151.48	4.82	6.38
	25	27.61	20.86	122.09	4.42	5.85
2%	0	31.61	23.88	148.39	4.69	6.21
	5	33.13	25.03	160.43	4.84	6.40
	10	36.17	27.32	183.06	5.06	6.70
	15	38.67	29.21	202.04	5.22	6.91
	20	32.14	24.28	157.34	4.89	6.48
	25	28.13	21.25	130.49	4.63	6.14

Table 8: Performance of Regression Modal (RM)

Sl.No.	% of fiber	% of replacement	Exp. Bearing strength(N/mm^2)	Bearing strength (N/mm^2) as per RM	Exp/RM
1	0%	0	134.90	135.56	0.99
2		5	147.99	147.18	1.00
3		10	172.26	171.94	1.00
4		15	188.94	189.01	0.99
5		20	145.22	145.25	0.99
6		25	114.47	114.54	0.99
7	1%	0	141.10	141.09	1.00
8		5	151.84	151.60	1.00
9		10	178.28	178.23	1.00
10		15	193.99	194.00	0.99
11		20	151.48	151.24	1.00
12		25	122.09	122.19	0.99
13	2%	0	148.39	148.39	1.00
14		5	160.43	160.42	1.00
15		10	183.06	183.17	0.99
16		15	202.04	201.60	1.00
17		20	157.34	157.32	1.00
18		25	130.49	128.46	1.01

6.6 Failure Mode Analysis

For all cubes compression test was conducted. The 0% fibres concrete cubes were shown lower load when compared with cubes containing with 1 and 2%. Among the1 and 2% fibre cubes the cubes with 2% showed higher load carrying capacity. In 0% fibre cubes, the concrete was peel off at edges, whereas the cubes containing fibres showed the integrity and as percentage of fibre increases the crack with and less damage was observed during experimentation .For each mix three cubes were tested for bearing strength with bearing ratio 15.In all the cubes during experimentation radial cracks were observed and this type of cracks were also observed by S.A.Al-Taan and J.A.Al-Hamdony [22]) for steel fibre concrete. The dimensional stability is more for higher percentage concrete cubes when compared with other percentage fibres and also the crack width is decreased as the % of fibre content increases. The tested cube for bearing strength can be observed in fig.2

Fig.2: Tested cube (bearing test)

7. Conclusions

From the present experimental work the following conclusions were drawn.

1. The optimum dosage for silica fume is found to be 15%. At this stage compressive and bearing strengths were increased when compared with other replacements.
2. At first crack state and ultimate stages, the % of increase is about to 6 to 24% for 15% silica fume replacement when compared with reference concrete.
3. With incorporation of steel fibers (i.e., 1 and 2%) in the concrete mixes the compressive and bearing strengths were increased when compared with respective replacement of silica fume.
4. For bearing ratio of 15 (i.e., plate size 38.7mm) at first crack and ultimate stages the % of increases about 10 to 40% for 15% replacement of silica fume when compared with reference concrete.
5. The IS and ACI codes underestimates the bearing strengths for different bearing ratios.
6. For better estimation of bearing strengths, few regression models were evaluated and tested for the results.
7. Radial cracks were observed for all cubes in the bearing test and the dimensional stability was noticed for fiber mix cubes.

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