

Investigation on Hardened properties of Concrete with Silica fume as Partial Replacement of Cement

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ABSTRACT: Industrial by products such as fly ash, palm oil ash, blast furnace slag, steel slag etc. can be utilised to improve the fresh and hardened properties of concrete. The use of Portland cement increases the amount of CO₂ emissions causing global warming. Silica fume, an ultra fine powder collected as a by-product of silicon & ferrosilicon production. The main objective of this research is to investigate the effect of Silica fume as partial replacement of Ordinary Portland Cement (OPC) on hardened properties of M30 concrete and in conjunction with superplasticizers. The properties include compressive Strength, Flexural Strength, Split Tensile strength, Modulus of Elasticity and workability to be studied. The replacements levels of OPC by silica fume were 0%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20%. The water binder ratio was kept at 0.45 for all cases. Specimens such as cubes, beams and cylinders were cast for various proportions and tested at the age of 3, 7 and 28 Days.

KEYWORDS: Silica fume, Compressive strength, Flexural Strength, Split Tensile strength, Modulus of Elasticity.

I. INTRODUCTION

Now a day we are facing a serious environmental problem called global warming, which is due to increase in the evolution of green house gases, including CO₂ from production of cement. To reduce the amount of CO₂ cement usage has to be decreased with the use of supplementary cementitious materials in concrete. To produce ecofriendly cementitious materials various researches has been done by using supplementary materials like Fly ash, Silica fume, Ground granulated blast furnace slag, cement kiln dust, rice husk ash, ceramic powder, copper slag, steel slag etc to reduce cost of energy, environmental pollution and natural resources. The materials, used are industrial waste products also creates environment disposal problem and are hazardous to environment. Recently, the utilization of highly pozzolanic materials in construction increases and this trend is expected to continue in the years due to improvement in technology and for the desire of sustainable development.

Early research used an expensive additive called fumed silica, consists of microscopic droplets of amorphous form of silica made by combustion of silicon tetrachloride in a hydrogen-oxygen flame. Silica fume on the other hand, is a very fine pozzolanic, amorphous material, a by-product of the production of elemental silicon or ferrosilicon alloys in electric arc furnaces. Silica fume is an ultrafine material with spherical particles less than 1 µm in diameter, the average being about 0.15 µm. This makes it approximately 100 times smaller than the average cement particle. Because of its chemical and physical properties, it is a very reactive pozzolan. Concrete containing silica fume can have very high strength and can be very durable. With the implementation of tougher environmental laws during the mid-1970s, silicon smelters began to collect the silica fume and search for its applications. Portland cement-based-concretes containing silica fumes had low porosities, and reduce negative environmental effect, and also would solve the landfill problem for the disposal of these wastes.

In this study, the effectiveness of by-product namely Silica fume (Micro silica) was developed as an alternative material to replace OPC. Calcium hydroxide (Ca (OH)₂) from the hydration process deteriorated the concrete, the

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

silica oxide content in Silica fume can react with calcium hydroxide ($\text{Ca}(\text{OH})_2$) and the pozzolanic reactions produce more calcium silicate hydrate (C-S-H) which is a gel compound as well as reducing the amount of calcium hydroxide. Thus, this contributes to the strength of the concrete produce stronger and denser concrete as well as enhanced the durability of the concrete. Silica fume cement-based concrete is a concrete produced by integrating Silica fume as a pozzolan in concrete. We will discuss the hardened properties of Silica fume concrete in different replacement levels. Strength properties such as Compressive strength, Flexural Strength, Split Tensile Strength, Workability and Elastic modulus at different ages will be studied, and compare with that of concrete containing 100% OPC as a control.

II. RELATED WORK

Venkat Reddy (2014)^[1] Studied and designed mix for high performance concrete using silica fume and super plasticizers. Experiments are conducted by varying silica fume percentage and super plasticizers in high performance concrete with replacement of silica fume 0 to 15%. Based on results, the optimum replacement is 15% of cement by weight. **Jeena Mathew (2012)**^[2] Studied the effect of silica fume on strength and durability properties of M35 grade concrete with partial replacement of cement. The different percentages of silica fume are 0, 5, 10, 15 and by 20%. The optimum 7 and 28-day compressive strength and flexural strength have been obtained in the range of 10-15 % silica fume replacement level. **Patil Shreekedar (2013)**^[3] studied the effect of mineral admixtures in mix proportioning of hpc. The results show that the maximum replacement level of Micro Silica is 15% for M60 grade High Performance Concrete. **Vinayagam.P (2012)**^[4] conducted experiments with silica fume and super plasticizers on high performance concrete with replacement of silica fume 0 to 15% and the HPC mixes are tested experimentally for workability, compression, split tension and flexure and concluded that the performance of the design mixes are very good. **Hooton**^[5] conducted experiments on replacement of cement with silica fume and studied physical properties and durability properties like freezing, thawing, and sulphate attack and alkali-silica reactivity. He concluded that 28 days compressive strength was maximum at 15% silica fume replacement at a w/b ratio of 0.35 with variable dosage of superplasticizers. **Faseyemi Victor Ajileye (2012)**^[6] made Investigations on micro silica (Silica fume) as Partial Cement replacement in Concrete and concluded that the maximum replacement level of silica fume is 10% for M30 grade of concrete. **Yogendran and Langan**^[7] investigated on high-strength silica fume concrete at a w/b ratio of 0.34 and percentage of replacement of silica fume 0 to 25, with the varying dosage of super plasticizer and reported that maximum replacement level of 15%. **Annadurai and ravichandran (2014)**^[8] conducted experiments for mix design of high strength concrete with admixtures, varying super plasticizer with a range 0.6 to 0.9% with an increment of 0.1% and concluded that addition of silica fume increases. **Debabrata Pradhan (2013)**^[9] Studied the properties of silica fume concrete such as compressive strength, compacting factor, and workability. He replaced cement by silica fume at different levels to know what percentage of silica fume gives the optimum value of compressive strength and for all replacements water to cement ratio is kept constant. The optimum percentage of silica fume is 15% by weight of cement. **Vishal S. Ghutke (2014)**^[10] Investigated the influence of silica fume to determine the optimum replacement percentages to use in Indian conditions and to fulfil various properties of concrete using silica fume. The optimum silica fume replacement percentage is varies from 10% to 15 % replacement level is concluded.

III. MATERIALS USED

In this present investigation materials used are cement, fine aggregate, Coarse aggregate, Silica fume, Super plasticizer.

2.1 Cement

Ordinary Portland cement of 53 grade confirming to IS: 12269-1987 was used. The properties of cement are shown in Table 1.

Table 1 properties of cement

Sl. No	Property	Result
1.	Normal consistency	31%
2.	Initial Setting Time	45 mins
3.	Specific Gravity	3.14
4.	Fineness of Cement	4%

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

2.2 Aggregate

Fine Aggregate: Locally available sand as per IS: 383-1987 was used. The sand was confirming to zone II. The properties of fine aggregate are shown in Table 2.

Table 2 Properties of fine aggregate

Sl. No	Property	Result
1.	Specific gravity	2.69
2.	Fineness modulus	2.645
3.	Zone	II

Coarse Aggregate

Crushed aggregate confirming to IS: 383-1987 was used. Aggregates of size 20mm and 12.5 mm of specific gravity 2.85 and fineness modulus 2.96 were used.

2.3 Silica Fume

Silica fume used was confirming to ASTM- C 1240 and was supplied by Astraa chemicals. The properties of fine aggregate are shown in Table 3.

Table 3: Properties of silica fume

Properties	Result
Specific Gravity	2.2
Bulk Density	720 Kg/m ³
Specific Surface	20 m ² /g
Particle size	<1 µm
colour	White
Sio ₂	(90.5-93)%

2.4 Super Plasticizer

In this investigation super plasticizer CONPLAST- 430 was used to improve the workability of concrete. The Properties of super plasticizer are shown in Table 4.

Table 4 Properties of super plasticizer

Specific Gravity	1.220-1.225
Chloride content	Nil
Air entrainment	Approximately 1%

IV. EXPERIMENTAL INVESTIGATION

The experimental program was designed to investigate the hardened properties i.e. compressive strength, split tensile strength, flexural strength and modulus of elasticity of M30 concrete with different replacement levels of ordinary Portland cement by silica fume are 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20% in conjunction with different percentages of superplasticizer.

3.1 Mix Proportioning

The total investigation was categorised in two stages. The mix proportions of all specimens for replacement of silica fume are tabulated in Table 5 and Table 6. First stage- The replacement levels of cement by silica fume were selected as 0%(control concrete), 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20%. Second stage-superplasticizers are commonly used to achieve the workability. Based on optimised value of silica fume, specimens are prepared by

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

varying percentages of super plasticizers as 0.25%, 5%, 0.75% & 1%. For all specimens, water/binder ration was kept as 0.45. The mix proportion adopted is 1: 1.407: 3.163.

Table 5 Mix proportions for M30 concrete

Mix proportion	Cement (kg/m ³)	Silica fume (kg/m ³)	Water (Kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)	W/C	SP (%)	Slump (mm)	Compaction factor
Control	400	0	180	563.35	1265.52	0.45	0	50	0.89
SF 2.5%	390	10	180	563.35	1265.52	0.45	0	46	0.89
SF 5%	380	20	180	563.35	1265.52	0.45	0	45	0.9
SF 7.5%	370	30	180	563.35	1265.52	0.45	0	45	0.89
SF 10%	360	40	180	563.35	1265.52	0.45	0	40	0.91
SF 12.5%	350	50	180	563.35	1265.52	0.45	0	30	0.92
SF 15%	340	60	180	563.35	1265.52	0.45	0	10	0.92
SF 17.5%	330	70	180	563.35	1265.52	0.45	0	10	0.91
SF 20%	320	80	180	563.35	1265.52	0.45	0	0	0.92

Table 6 Mix proportions of M30 concrete with different percentages of SP

Specimen ID	Silica fume (%)	Cement (kg/m ³)	Silica fume (kg/m ³)	Water (Kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (Kg/m ³)	W/C	SP (%)	Slump (mm)	Compaction factor
SF-I	12.50%	350	50	180	563.35	1265.52	0.45	0	30	0.92
SF-II	12.50%	350	50	180	563.35	1265.52	0.45	0.25	20	0.94
SF-III	12.50%	350	50	180	563.35	1265.52	0.45	0.5	130	0.948
SF-IV	12.50%	350	50	180	563.35	1265.52	0.45	0.75	130	0.95
SF-V	12.50%	350	50	180	563.35	1265.52	0.45	1	140	0.956
SF-I A	15.00%	340	60	180	563.35	1265.52	0.45	0	10	0.92
SF-II A	15.00%	340	60	180	563.35	1265.52	0.45	0.25	20	0.92
SF-III A	15.00%	340	60	180	563.35	1265.52	0.45	0.5	50	0.92
SF-IV A	15.00%	340	60	180	563.35	1265.52	0.45	0.75	90	0.942
SF-V A	15.00%	340	60	180	563.35	1265.52	0.45	1	130	0.96

3.2 Experimental Procedure

Specimens of standard sizes of (100mmx100mmx100mm) cubes were used to determine the compressive strength of concrete. Three specimens were tested for 3,7,28 days with each proportion of silica fume replacement and standard cylinders of (150mmx300mm) and prisms of (100mmx100mmx500mm) were used to determine the compressive strength of concrete, split tensile strength and flexural concrete. Total 180cubes were casted for compressive strength, 15 prisms for flexural strength, 15 cylinders for Split tensile strength and 6 cylinders for Modulus of Elasticity. The specimens were tested for 3,7,28 days respectively.

V. RESULTS AND DISCUSSIONS

4.1 Compressive Strength

Table 7 shows the development of compressive strength of control concrete and concrete with silica fume content of 0, 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20% as cement replacement. The test was carried out confirming to IS 516-1959 to obtain the compressive strength of concrete at the age of 3,7 and 28 days. There is a significant improvement in the strength of concrete because of high pozzolanic nature of silica fume. The increase in compressive strength up to replacement of 15% was observed and then decreased. The percentage increase in compressive strength was up to 45.85%, 7.5 and 16.31% at 3 days, 7 days and 28 days respectively for SF-I type (12.5% silica fume & 0% SP) compared to control concrete. The maximum percentage increase in compressive strength was up to 88.81%, 51.5

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

and 32% at 3 days, 7 days and 28 days respectively for SF-V type (12.5% silica fume & 1% SP). The percentage increase in compressive strength was up to 57.32%, 15.36 and 18.49% at 3 days, 7 days and 28 days respectively for SF-IA type (15% silica fume & 0% SP). The maximum increase in compressive strength was up to 97.77%, 64.36 and 52.19% at 3 days, 7 days and 28 days respectively for SF-VA type (15% silica fume & 1% SP). The maximum value of Compressive strength is 46.66N/mm^2 was obtained at 15% replacement level of cement by weight of silica fume with 1% SP at 28 days of testing.

Table 7 shows the compressive strength of concrete

Percentage (%) of Silica fume	Compressive Strength(N/mm^2)		
	3 Days	7 Days	28 Days
0	14.83	22	30.66
2.5	18.33	20	28.16
5	20.6	22	31.66
7.5	20.5	23.16	33
10	20.8	23.83	34.83
12.5	21.63	23.66	35.66
15	23.33	25.33	36.33
17.5	18.33	20.66	30
20	17.5	20.88	29.33

Table 8 shows the compressive strength of concrete

Specimen ID	Compressive Strength (N/mm^2)		
	3 Days	7 Days	28 Days
SF-I	21.63	23.66	35.66
SF-II	20.33	30.66	35.16
SF-III	23.33	30	36.33
SF-IV	25	31	38.18
SF-V	28	33.33	40.5
SF-I A	23.33	25.33	36.33
SF-II A	28.83	33.5	36.66
SF-III A	28.83	34.26	43.33
SF-IV A	26	33.46	44.5
SF-V A	29.33	36.16	46.66

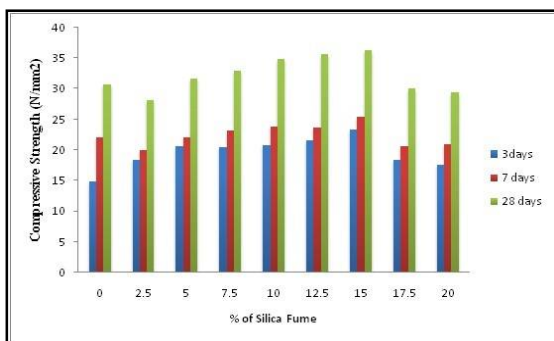


Fig 1 Compressive Strength of M30 Grade Concrete with various proportions of Silica fume

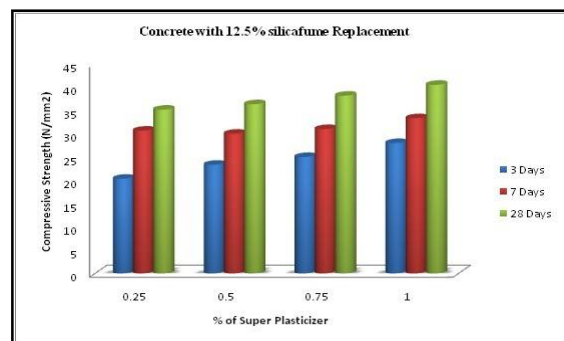


Fig 2 Effect of SP on Compressive Strength of 12.5% silica fume replaced concrete

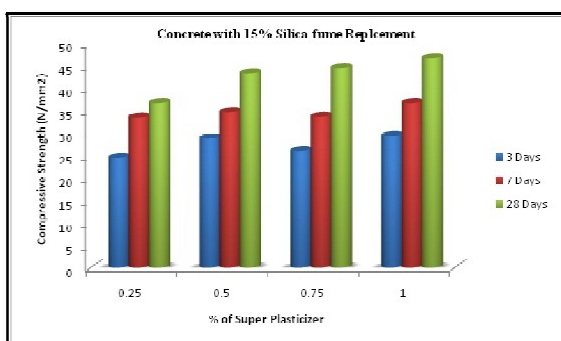


Fig 3 Effect of SP on Compressive Strength of 15% silica fume replaced concrete

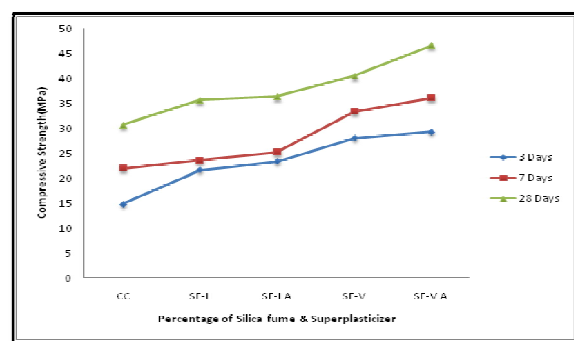


Fig 4 Effect of SP & Silica fume on Compression Strength of concrete

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

4.2 Flexural Strength

The results of flexural strength of control concrete and silica fume replaced concrete were presented in Table 9 & Fig 5. The test was carried out confirming to IS 516-1959 to obtain the flexural strength of concrete at the age of 3,7 and 28 days. The percentage increase in Flexural strength was up to 23.79%, 18.435 and 30.29% at 3 days, 7 days and 28 days respectively for SF-I type. The maximum percentage increase in Flexural strength was up to 31.8%, 33.24 and 39.91% at 3 days, 7 days and 28 days respectively for SF-V type. The increase in Flexural strength was up to 27.97%, 29.88 and 33.49% at 3 days, 7 days and 28 days respectively for SF-I A type. The maximum increase in Flexural strength was up to 49.52%, 43.80 and 47.86% at 3 days, 7 days and 28 days respectively for SF-VA type. The maximum Flexural strength is observed at 15% replacement of silica fume with 1% SP at 28 days of testing.

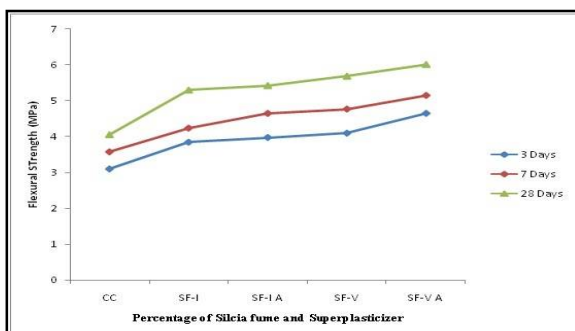


Fig 5 Effect of SP & Silica fume on Flexural Strength of concrete

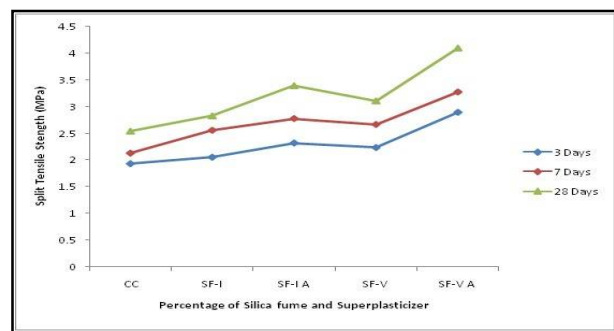


Fig 6 Effect of SP & Silica fume on Split Tensile Strength of concrete

4.3 Split Tensile Strength

The results of split Tensile Strength of control concrete and silica fume replaced concrete were presented in Table 9 & Fig 6. The test was carried out confirming to IS 516-1959 to obtain the flexural strength of concrete at the age of 3,7 and 28 days. The percentage increase in Split Tensile strength was up to 6.18%, 20.18 and 13.77% at 3 days, 7 days and 28 days respectively for SF-I type. The maximum increase in Split Tensile strength was up to 19.85%, 30.52 and 33.66% at 3 days, 7 days and 28 days respectively for SF-V type. The percentage increase in Split Tensile strength was up to 15.46%, 25.35 and 22.44% at 3 days, 7 days and 28 days of curing for SF-IA type. The maximum percentage increase in Split Tensile strength was up to 49.23%, 53.99 and 61.5% at 3 days, 7 days and 28 days respectively for SF-VA type. The maximum Flexural strength is observed at 15% replacement of silica fume with 1% SP at 28 days of testing.

Table 9 shows the flexural strength and split tensile strength of control concrete and silica fume replaced concrete

Specimen ID	Flexural Strength(N/mm ²)			Split Tensile Strength(N/mm ²)		
	3 Days	7 Days	28 Days	3 Days	7 Days	28 Days
CC	3.11	3.58	4.06	1.94	2.13	2.54
SF-I	3.85	4.24	5.2936	2.06	2.56	2.829
SF-IA	3.98	4.65	5.42	2.325	2.78	3.395
SF-V	4.1	4.77	5.68	2.24	2.67	3.11
SF-VA	4.65	5.15	6.0035	2.895	3.28	4.102

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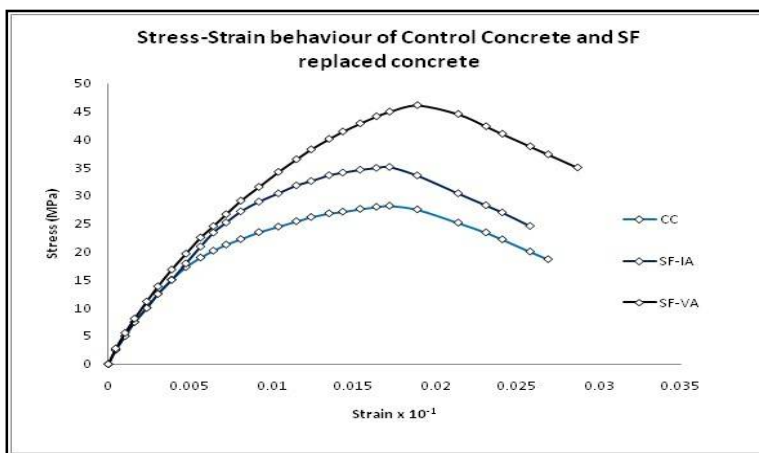
Vol. 5, Issue 2, February 2016

4.4 Modulus of Elasticity

The Stress Strain behaviour of control concrete and silica fume replaced concrete presented in Fig 7. The test was carried out confirming to obtain flexural strength of concrete at the age of 28 days. The cylinders were tested using Universal Testing Machine (UTM) of capacity 1000KN. From the observations, the optimum silica fume percentage is 15%. The modulus of Elasticity of control concrete is 24915.6 N/mm^2 , for 15% silica fume & 0% SP concrete the value of modulus of elasticity is 30379.17 N/mm^2 , for SF-VA type concrete the value of modulus of elasticity is 31348.12 N/mm^2 . The increase in modulus of elasticity was up to 21.92% and 25.82% at 28 days for SF-IA, SF-VA type concrete mixes.

The theoretical value of E, for $f_{ck}=30 \text{ N/mm}^2$, $E_c = 4700 \sqrt{f_{ck}} = 25743 \text{ N/mm}^2$

Fig 7 Stress-Strain behaviour of Control Concrete & SF replaced concrete & **Table 10** Secant modulus (E_c) values for M30 grade concrete



Designation	Secant modulus
Control Concrete	24915.625 N/mm^2
SF-I A	30379.17 N/mm^2
SF-V A	31348.12 N/mm^2

4.5 Workability of concrete

Fig 8 & 9 shows the variation of workability of silica fume replaced concrete and optimized concrete with super plasticizer. Workability is defined as the properties of freshly mixed concrete which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished. The workability was measured by conducting slump cone test and compaction factor test in accordance with IS: 1199- 1959. The trials were carried out to improve the workability and cohesiveness of the fresh concrete by incorporating a super plasticizer. Super plasticizer was added in range of 0.25 to 1% by weight of cementations materials to improve the workability. The results show that incorporation of super plasticizer along with silica fume in control concrete greatly influences the performance of super plasticizers. The slump value increases from 50mm to 140mm, 130mm for SF-V and SF-V A type concrete.

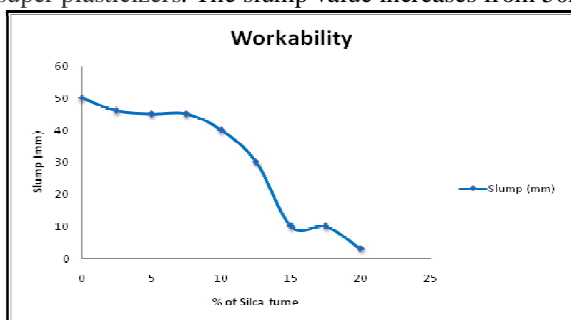


Fig 8 Workability of concrete with Silica fume

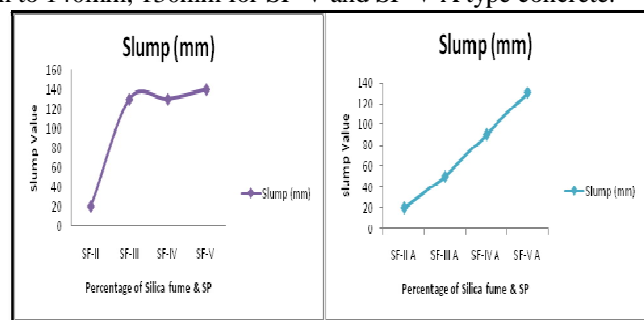


Fig 9 Workability of concrete with SF & SP

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

VI. CONCLUSIONS

From the results it is conclude that the silica fume is a better replacement of cement. The rate of strength gain in silica fume concrete is high. After performing all the tests and analysing their result, the following conclusions can be derived:

1. Cement replacement up to 15% with SF, leads to increasing compressive strength, split tensile strength and flexural strength. The optimum value of compressive strength is varies from 12.5% to 15% replacement of silica fume, beyond 15% there is a decrease in compressive strength was observed.
2. There is a decrease in workability as the replacement level of micro silica increases, and increase in workability as the percentage of superplasticizer increases from 0.25 to 1.
3. The maximum increase in compressive strength was up to 57.32%, 15.36 and 18.49%, Flexural strength was up to 27.97%, 29.88 and 33.49% and Split Tensile strength was up to 19.85%, 30.52 and 33.66% at 3 days, 7 days and 28 days respectively for SF-I A type.
4. The maximum increase in compressive strength was up to 97.77%, 64.36 and 52.19% Flexural strength was up to 49.52%, 43.80 and 47.86% and Split Tensile strength was up to 49.23%, 53.99 and 61.5% at 3 days, 7 days and 28 days respectively for SF-VA type.
5. The maximum value of Compressive strength, Flexural strength, Split Tensile strength was obtained at 15% replacement level of cement by weight of silica fume in conjunction with 1% superplasticizer is 46.66N/mm², 6.0035N/mm² and 4.102N/mm².
6. The maximum value of modulus of elasticity is 31348.12N/mm² for SF-VA type concrete at 28 days. The increase in modulus of elasticity was up to 21.92% and 25.82% at 28 days for SF-V, SF-VA type concrete mixes.
7. The maximum percentage of cement replacement by SF is 15% for achieving maximum Compressive, Split tensile and Flexural strength and Modulus of elasticity.

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