Investigation of High-Strength Concrete Using Fly Ash and Silica Fume

Dr. Rakesh Srivastava[1], Yogendra Kumar, Rupesh Kumar, Saurabh Kumar, Sonam Gupta, Vijay Kumar and **Vividh Mahajan**
Department of Civil Engineering, Ajay Kumar Garg Engineering College, 27 Kmstone, NH-24, Adhyatmik Nagar, Ghaziabad 201009 UP India
[1]rs.akgec@gmail.com

Abstract -- **The necessity of high-strength concrete is increasing because of the increasing demand of the construction materials in the construction industry. The main motive of this study is to use the waste materials which not only helps in getting them utilized in cement, concrete and other construction materials, but also has numerous indirect benefits such as saving in energy, and protecting environment from possible pollution effect. High-strength concrete is a construction material with improved properties like strength, durability etc. than ordinary concrete. High-strength concrete can be achieved through proper mix design process. Therefore, mix design plays an important role in the concrete technology. High -strength concrete can be achieved through using good quality of ingredient materials, following proper methods of casting and testing and calculations of mix design, and using comparatively low water-cement ratio. In this research work, super plasticizer is used as a chemical admixture to the concrete.**

This work is carried out to study the mix design of high-strength concrete with partial replacement fly ash and silica fume in various proportions. We propose the mix proportion of M100 in terms of cement, fine aggregates and coarse aggregates including fly ash and silica fume percentage by replacing of cement and super plasticize percentage by replacing of water. Compressive strength; rebound hammer and ultra-pulse velocity test was conducted on 7 days and 28 days.

Keywords: High-strength concrete, Compressive strength, Super plasticizer, Silica fumes

I. INTRODUCTION

CONCRETE is most commonly used and preferred material for construction purpose throughout the world as it is durable, easy to make at constructional site, easy to transport and place and it can be moulded into any desired shape and size. The main ingredient of concretes is easily available in most of the places which makes concrete even more popular according to IS 456:2000 - Plain and Reinforced concrete- code of practice ordinary concrete, standard concrete and high strength concrete (HSC).

Ordinary concrete and standard concrete may be defined as the concrete with specified characteristics compressive strength of 150mm^{3}cube at 28 days between 10-20N/mm^{2}and 25-55N/mm^{2}respectively. The high-strength concrete may be defined as the concrete with specified characteristics strength of 150mm^{3}cube at 28 days between 60-80 N/mm^2.

Disposal of material like fly ash and silica fumes is becoming a serious problem for environment and economic consideration. Use of such material as replacement of conventional materials can achieve twin objectives of "waste disposal and natural resource conservation together". The replacement of cement by pozzolonic material in a concrete often achieves cost saving and imparts specific engineering properties to the finishes product.

To use pozzolonic material effectively and economically, it is important to understand the difference of properties between cement and pozzolonic material. In this modern era which is facing acute shortage for raw material, industry needs faster development of high strength concrete so that the construction work can be completed within the given specified time. The demand is attained by high early strength cement use of flow water cement ratio through the use of increased cement content by reduced water content.

There are several benefits of silica fumes and fly ash in concrete some of them are as follows:
- High early compressive strength.
- High tensile flexural strength and modulus of elasticity.
- Higher bond strength.
- Reduction in cost of construction.

II. OBJECTIVE

The main objective of this project is to use the waste materials which not only helps in getting them utilized in cement, concrete and other construction materials, but also has numerous indirect benefits such as reduction in land fill cost, saving in energy, and protecting environment from possible pollution effect. The constituent materials used in this investigation were procured from local sources. Some other objectives are:

- To obtain the best mix proportion for high-strength concrete by partial replacement of silica fume and fly ash.

- To reduce the size of structural member and early removal of formwork.
- To find economical solution for high cost construction material.
- Study of the effect of using silica fumes and fly ash in concrete and its benefits.
- Improve the overall durability and long-term performance of concrete structures.
- An approach towards the use of the alternative materials as concrete admixture.

III. LITERATURE REVIEW

Several researches are needed for better understanding of the behaviour of silica fumes and fly ash in concrete. However, the research works carried out for the high-strength concrete are found to be limited. Following studies have been done so far in the concerned field:-

In 1999, Poon *et al.* concluded that concrete prepared with large volume of low calcium fly ash is cost effective as compared to conventional flexible pavement. About 50% of the cement hydrated at the age of 7 days. From 7 days to 90 days, the increase in degree of hydration was not significant. In 2002, Skripkiunas *et al.* found that: The optimum content of naphthalene formaldehyde super-plasticizer in HSC mixture is 1, 1.5%. Silica fumes increase the degree of cement hydration and decreases $Ca(OH)_2$ quantity in a hardened concrete. In 2005, Safiuddin and Zain concluded that silica fumes provide better stability and good flow properties than fine aggregate because it's segmented the bleed water channels and acted as ball bearings. In 2011, Laskar concluded that it is always difficult to develop a mix design method that can be used universally because same properties of fresh and hardened concrete can be achieved in different ways from same materials. Composition of material and characteristics vary from place to place. In 2012, Sreenivasulu and Shrinivasha Rao concluded that the strength of the concrete may be still increased by reducing water/cement ratio and increase the percentage of silica fumes. In 2012, Turk *et al.* concluded that the water sorptivity values of SCC specimen decrease with increase in the replacement of silica fumes from 5 to 20% whilst the water sorptivity value of Self compacting concrete specimens with fly ashsystematically increased with increase in the replacement level of Fine Aggregate from 25 to 40%. In 2013, Muhit *et al.* concluded that Water permeability and strength characteristics of HPC can be improved considerably by replacing OPC with either silica fumes or fly ash. Lowest water permeability 15 mm for fly ash was obtained at 20% by weight. Lowest penetration of water is 11mm. In 2014, Kumar *et al.* found that Durability characteristics such as water absorption, permeability, sulphate attack resistance and abrasion resistance are low for the fly ash and silica fume based concrete materials as compared with conventional high-performance concrete. In 2016, Kumar and Kisku concluded that Pozzolonic material have significant influence on mechanical properties of concrete.

The replacement of cement with silica fumes is environment friendly in nature. One of the biggest benefits of using silica fumes is reduction in CO_2 emissions, which is main cause of Green House effects. In 2017, Panda and Parhi, concluded that Ratio 1:0.76:2.47 with super-plasticizer of cement used and water cement ratio 0.35 gives satisfactory results. Proportion can be used to produce concrete of grade M60. In2017, Lidoo *et al.* concluded that Supplementary Cementious Material like Alccofine play a significant role in Strength Development of the Concrete Mixes. 10% addition of alccofine gives better results. In 2017, Meeravali and Brahmachari concluded that Silica fumes content-4, 6, 8 & 10% super plasticizer 4 - 8% respectively gained 107 Mpa after 28 days by using 10% silica fumes and 8% super plasticizer.

IV. MATERIAL USED

Cement: It is one of the most important ingredients of concrete. It acts as a binder element in the concrete. The cement used in this study is Portland Pozzalana cement (PPC). Portland Pozzolana cement is integrated cement which is formed by synthesizing OPC cement with pozzolanic materials in a certain proportion.

Properties of PPC:

- Initial setting time = 30 min (minimum)
- Final setting time = 600 min (maximum).
- At 3 days 13MPa (minimum)
- At 7 days 22 MPa (minimum)
- At 28 days 33 MPa (minimum)
- Drying shrinkage should not be more than 0.15%
- Fineness should not be less than 300 m^2/kg
- Initial strength of PPC is less but final strength is equal to the 28 days strength of OPC.

Coarse Aggregate : The coarser the aggregate, the more economical the mix. Larger pieces offer less surface area of the particles than an equivalent volume of small pieces. Use of the largest permissible maximum size of coarse aggregate permits a reduction in cement and water requirements. Using aggregates larger than the maximum size of coarse aggregates permitted can result in interlock and form arches or obstructions within a concrete form.

TABLE 1 -- PROPERTIES OF COARSE AGGREGATE

Property	Observed value
Specific gravity	2.76
Bulk density	1534 kg/m^3
Loose density	1457 kg/m^3
Maximum Size of aggregate	Upto 20 mm

Fine Aggregate: Fine aggregates (FA) with a rounded particle shape and smooth texture have been found to require less mixing water in concrete and for this reason are preferable in HSC. However, it is sometimes helpful to increase the fineness modulus (FM) as the lower Fineness modulus of Fine Aggregate can give the concrete a sticky consistency (*i.e.* making concrete difficult to compact) and less workable fresh concrete with a greater water demand.

TABLE 2 -- PROPERTIES OF FINE AGGREGATE

Property	Observed value
Specific gravity	2.16
Bulk density	1587 kg/m^3
Loose density	1465 kg/m^3
Water absorption	1 %

Water: Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. In practice, very often great control on properties of cement and aggregate is exercised, but the control on the quality of water is often neglected. Since quality of water affects the strength, it is necessary for us to go into the purity and quality of water. If water is fit for drinking it is fit for making concrete. This does not appear to be a true statement for all conditions.

Superplasticizer: More water reducing admixture and it is called as super plasticizers, used for improving the flow and workability for lower water-cement ratios without sacrifice in the compressive strength. In this study, we have used Conplast SP430.

Conplast SP430 is a chloride free, superplasticising admixture based on selected sulphonated naphthalene polymers. It is supplied as a brown solution which instantly disperses in water. Conplast SP430 disperses the fine particles in the concrete mix, enabling water content of concrete to perform more effectively. The very high levels of water reduction possible allow major increases in strength to be obtained.

TABLE 3 -- PROPERTIES OF SUPER PLASTICIZER

Appearance	Brown liquid
Specific gravity	Typically 1.20 at 20°C
Chloride content	Nil to BS 5075
Air entrainment	Typically less than 2% additional air entrained at normal dosages.
Alkali content	Typically less than 72.0 g. Na_2O equivalent/liter of admixture.

Silica Fume: Silica fume (SF) is a by-product of the melting process used to produce silicon metal and ferrosilicon alloys. The main characteristics of SF are its high content of amorphous SiO_2 ranging from 85 to 98%, mean particle size of 0.1 – 0.2 micron (approximately 100times smaller than the average cement particle) and its spherical shape. Because of its extreme fineness and high silica content, SF is a highly effective pozzolanic material. The use of SF as replacement of a part of the cement gives considerable strength gain.

Fly Ash: The use of fly ash in Portland cement concrete (PCC) has many benefits and improves concrete performance in both the fresh and hardened state. Fly ash use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. Fly ash use is also cost effective. When fly ash is added to concrete, the amount of Portland cement may be reduced.

V. MIX DESIGN

In India, generally IS Codes are followed for designing a concrete mix. IS:10262-1982 Indian Standard Recommended Guidelines for Concrete Mix design has been revised with Indian Standard code for concrete mix proportioning - Guidelines *i.e.*, IS10262:2009. But IS-10262:2009 is only applicable for ordinary and standard grade concrete**.**

Under this work "Investigation of high strength concrete using silica fume & fly ash" we have targeted a strength of 100MPa. Also in this work we have taken Portland pozzolana cement in which a 30% fly ash is already included.

Mix Proportion

SAMPLE NO. 1

Mix design proportion for 0.25 W/C ratio, super plasticizer = 1.5% of cementious material and silica fumes is not taken in this trial:

TABLE 3 -- PROPERTIES OF SUPER PLASTICIZER

CEMENT	FINE AGGREGATE	COARSE AGGREGATE	SILICA FUMES	SUPER PLASTICIZER	WATER
624.8	616.89	956.43	N.A.	9.372	142
1	0.987	1.53	N.A.	0.015	0.227

SAMPLE NO. 2

Mix design proportion for 0.25 W/C ratio, super plasticizer = 1.5% of cementious material and silica fumes = 12%.

TABLE 5 -- PROPORTION OF SAMPLE 2

CEMENT	FINE AGGREGATE	COARSE AGGREGATE	SILICA FUMES	SUPER PLASTICIZER	WATER
550	611.39	947.49	74.976	9.37	142
1	1.11	1.72	0.1363	0.0170	0.258

SAMPLE NO. 3
Mix design proportion for 0.23 W/C ratio, super plasticizer = 2% of cementious material & silica fumes =14%:

TABLE 6 -- PROPORTION OF SAMPLE 3

CEMENT	FINE AGGREGATE	COARSE AGGREGATE	SILICA FUMES	SUPER PLASTICIZER	WATER
584.06	588.06	911.74	95.07	13.58	142
1	1.01	1.56	0.163	0.0233	0.243

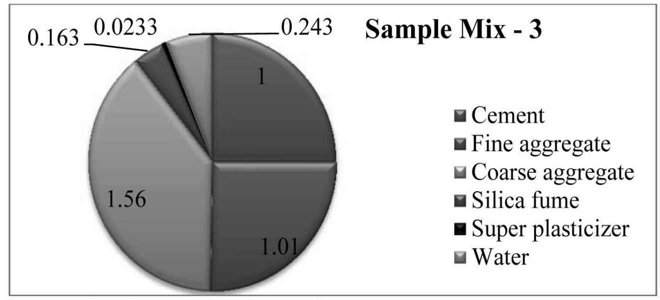

Figure 3. Distribution of ingredients in concrete, Sample Mix 3.

SAMPLE NO. 4
Mix design proportion for 0.23 W/C ratio, super plasticizer = 4% of cementious material & silica fumes = 15%:

TABLE 7: PROPORTION OF SAMPLE 4

CEMENT	FINE AGGREGATE	COARSE AGGREGATE	SILICA FUMES	SUPER PLASTICIZER	WATER
577.26	576.97	894.55	101.87	27.16	142
1	0.999	1.549	0.176	0.074	0.246

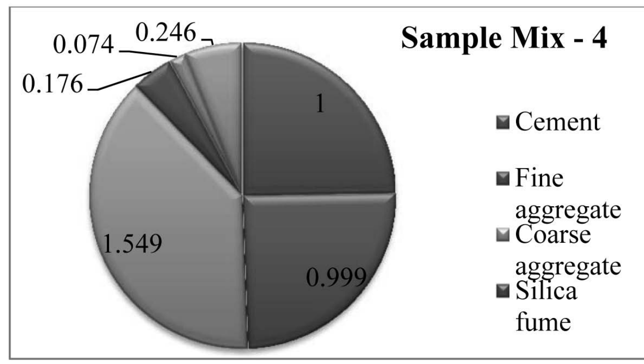

Figure 4. Distribution of ingredients in concrete, Sample Mix 4.

B. DISTRIBUTION OF INGREDIENTS IN CONCRETE
The distribution of ingredients in concrete of Sample mix 1, Sample mix 2, Sample mix 3 and Sample mix 4 are shown in the following charts.

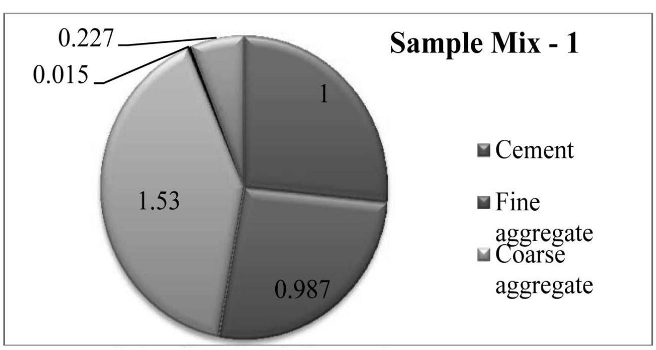

Figure 1. Distribution of ingredients in Concrete, Sample Mix 1.

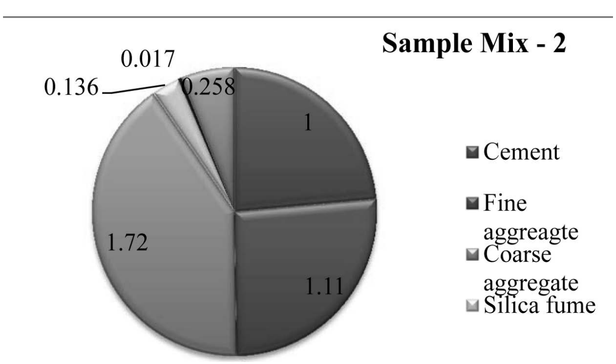

Figure 2. Distribution of ingredients in concrete, Sample Mix 2.

VI. RESULTS

The compressive strength of hardened concrete is considered one of the most important properties and is often used as an index of the overall quality of concrete.

Sample-1:
The average compression strength of the specimens with W/C ratio 0.25, Super Plasticizer -1.5% and without using silica fume is shown in the table 13. In this trial mix also the required strength was not achieved.

TABLE 8 -- AVERAGE STRENGTH OF CUBES IN SAMPLE 1

DESCRIPTION	VALUE		
Age of Strength in days	7		28
No. of cube	3		3
Cube Strength (N/mm^2) Cube 2 Cube 3	Cube 1	34.17	52.11
	35.18	54.28	
	37.43	55.67	
Avg. strength(N/mm^2)	**35.59**		**54.02**

TABLE 9 -- DIFFERENT TEST VALUES AFTER 28 DAYS IN SAMPLE 1

No of cube	Compressive Strength (in MPa)	Rebound Number	Ultrasonic pulse velocity (km/s)
Cube 1	52.11	62.5	3.65378
Cube 2	54.28	68.3	3.75744
Cube 3	55.67	71.9	4.28443

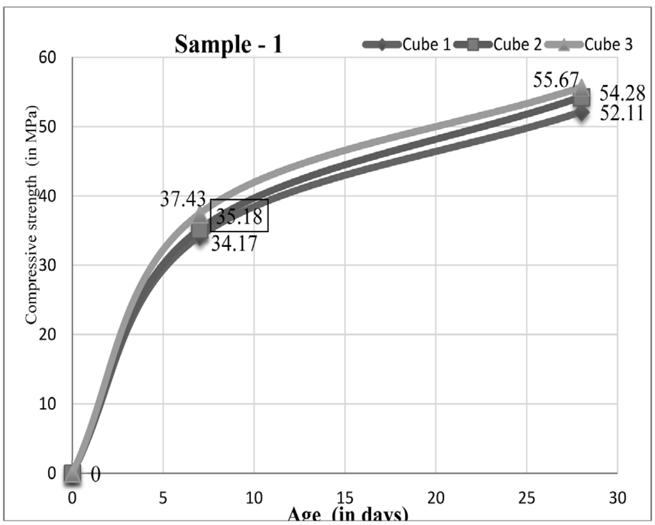

Figure 5. Compressive strength after 7 and 28 days (Sample- 1).

Sample -2:
The average compression strength of the specimens using 12% silica fume replacement by cementious material, W/C ratio - 0.25 and Super Plasticizer - 1.5% is shown in table 11.It was identified that the required strength was not achieved.

TABLE 10 -- AVERAGE STRENGTH OF CUBES IN SAMPLE 2

DESCRIPTION		VALUE	
Age of Strength in days		7	28
No. of Cube		3	3
Cube Strength (N/mm²)	Cube 1	35.53	57.13
	Cube 2	37.99	58.35
	Cube 3	38.61	60.33
Avg. strength(N/mm²)		**37.38**	**58.60**

TABLE 11 -- DIFFERENT TEST VALUES AFTER 28 DAYS IN SAMPLE 2

Cube No.	Compressive Strength (in MPa)	Rebound Number	Ultrasonic pulse velocity (km/s)
Cube 1	57.13	72.4	3.79864
Cube 2	58.35	66.9	4.14336
Cube 3	60.33	74.7	4.65563

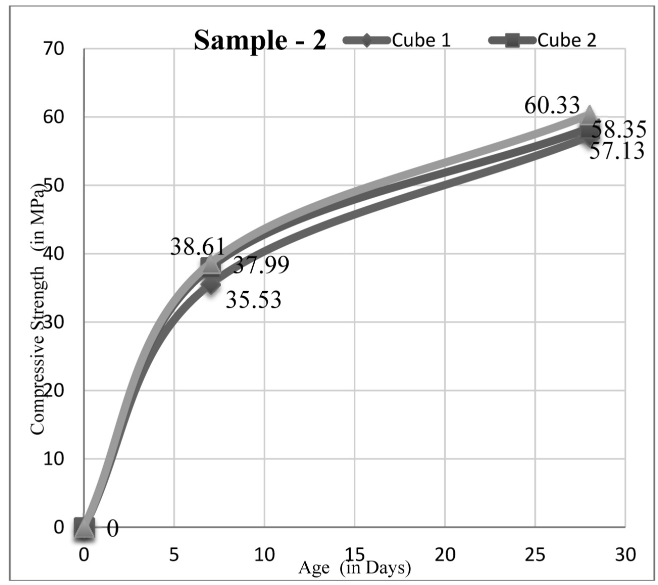

Figure 6. Compressive strength after 7 and 28 days (Sample- 2).

Sample- 3:
The table 13 shows that the replacement of cement with 14% silica fume, W/C ratio- 0.23 and Super Plasticizer - 2% still we did not achieve the required strength of the concrete at 28 days.

TABLE 12 -- AVERAGE STRENGTH OF CUBES IN SAMPLE 3

DESCRIPTION		VALUE	
Age of Strength in days		7	28
No. of cube		3	3
Cube Strength (N/mm²)	Cube 1	50.72	76.08
	Cube 2	47.14	70.71
	Cube 3	51.83	76.89
Avg. strength(N/mm²)		**49.90**	**74.56**

TABLE 13 -- DIFFERENT TEST VALUES AFTER 28 DAYS IN SAMPLE 3

No of cube	Compressive Strength (in MPa)	Rebound Number	Ultrasonic pulse velocity (km/s)
Cube 1	76.08	68.5	3.98203
Cube 2	70.71	76.3	4.24935
Cube 3	76.89	71.5	4.14927

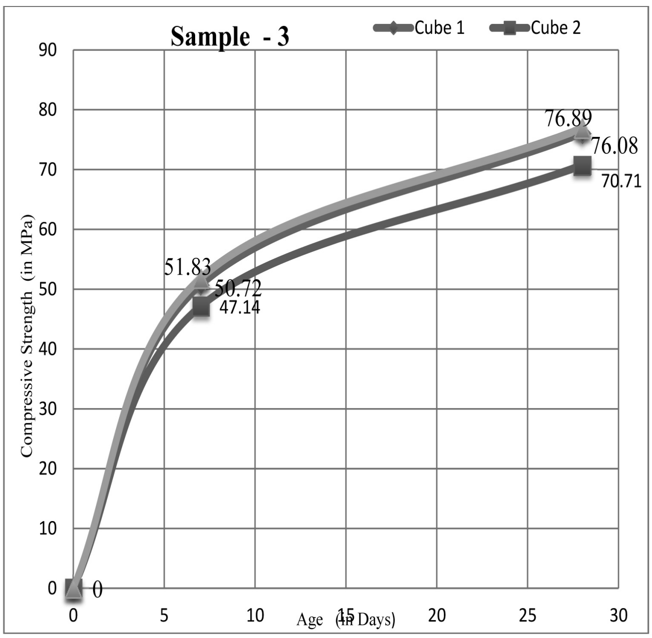

Figure 7. Compressive strength after 7 and 28 days (Sample- 3).

Sample- 4:

The table 15 shows that the replacement of cement with 15% silica fume, w/c ratio 0.23 & Super Plasticizer 4% still we did not achieve the required strength of the concrete at 28 days.

TABLE 14 -- AVERAGE STRENGTH OF CUBES IN SAMPLE 4

DESCRIPTION		VALUE	
Age of Strength in days		7	28
No. of cube		3	3
Cube Strength (N/mm²)	Cube 1	42.20	64.40
	Cube 2	48.40	72.60
	Cube 3	46.80	70.20
Avg. strength(N/mm²)		**45.80**	**69.06**

TABLE 15 -- DIFFERENT TEST VALUES AFTER 28 DAYS IN SAMPLE 4

No of cube	Compressive Strength (in MPa)	Rebound Number	Ultrasonic pulse velocity (km/s)
Cube 1	64.47	79.5	3.86519
Cube 2	72.69	86.5	4.28832
Cube 3	70.23	85.4	4.15758

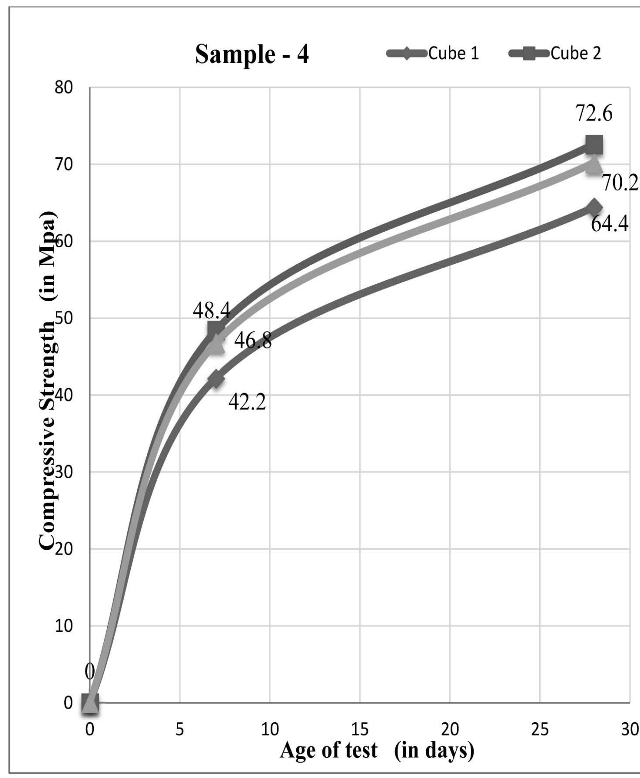

Figure 8. Compressive strength after 7 and 28 days (Sample- 4).

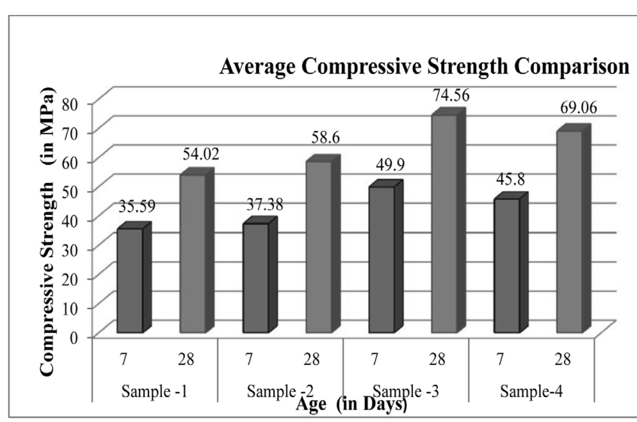

Figure 9. Average compressive strength in different trial mix design after 7 and 28 days of test.

VII. CONCLUSION

The present study was undertaken to develop High Strength Concrete and to investigate the compressive strength of concrete specimens with the addition of different percentages of silica fumes and Super plasticiser in concrete mix under different W/C ratio. The compressive strength test was performed after 7 and 28 days of curing of concrete specimen.

i. By using IS 10262:2009, mix combinations are prepared for M100 grade concrete having varying w/c ratio as 0.25 & 0.23 Silica fume (12% 14% & 15%) and Super plasticizer (1.5%, 2% and 4%).
ii. The maximum compressive strength obtained for w/c ratio - 0.23, 14% Silica Fume and 2% Super Plasticizer proportion is 74.56N/mm^2. It is possible to achieve the compressive strength of HSC up to M70 grade using proportion used in Sample no. 3, by following the IS 10262:2009 code specifications.
iii. Preparation of Sample mix and test the compressive strength at 7 days will give the actual idea about the mix proportion. 14 % silica fume 2% of super plasticizer gives better result.
iv. In terms of economy, replacement of cement with silica fume results in cost reduction considerably for large projects.
v. The replacement of Portland pozzolana cement with silica fume is environment friendly in nature. One of the biggest benefits of using silica fume is reduction in CO_2 emissions, which is the main cause of Green – house effect.

VIII. CONTRIBUTION OF PROJECT

The contribution of this project is not only in the field of theoretical aspect of construction but also have large practical implications as:

i. Producing economic concrete by reducing the cost of material.
ii. Eco-friendly.
iii. Increasing strength of concrete by using fly ash and silica fumes.
iv. Recycling and reusing waste effectively. Thus protecting the environment from possible pollution effect.

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Standards

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[13] IS code 3812- Guidelines for Fly ash.

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Dr. Rakesh Srivastava received BTech degree in Civil Engineering with honours from Harcourt Butler Technological Institute, Kanpur. He has done his ME (Hons.) and PhD in structures from Motilal Nehru National Institute of Technology, Allahabad. Apart from 23 years of experience in teaching and research, he has also worked as a Consultant in the field of Structural Engineering.

He worked at different positions in Engineering Colleges as Dean of Student Welfare, Dean Engineering and Controller of Examinations. Currently, working as Professor in Civil Engineering in Ajay Kumar Garg Engineering College, Ghaziabad.

He is a Fellow of Institution of Engineers (I). His areas of interest are in structural analysis and structural-related problems. His research interests include Concrete Technology, Structural Health Monitoring, piezo-electric sensor and transducer to various structural engineering-related problems and high-rise buildings/ structures.