

Investigations on Micro Silica (Silica Fume) as Partial Replacement of Cement in Concrete

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Abstract: *Now a day, we need to look at a way to reduce the cost of building materials, particularly cement is currently so high that only rich people and governments can afford meaningful construction. Studies have been carried out to investigate the possibility of utilizing a broad range of materials as partial replacement materials for cement in the production of concrete. This study investigated the strength properties of Silica fume concrete. Micro silica or silica fume is very fine non crystalline material. Silica fume is produced in electric arc furnace as a by product of the production of elemental silicon's or alloys containing silicon. It is usually a white coloured powder somewhat similar to Portland or some fly ash. silica fume is generally categorized as a supplementary cementitious material. Silica fume or micro silica was initially view as cement replacement material and can be used as pozzolanic admixtures. Admixture is defined as a material other than cement water and aggregate that is used as ingredient of concrete and is added to the batch immediately before or during mixing. Pozzolanic admixtures are siliceous or aluminous material which is themselves possess little or no cementitious value but will in finely divided form and in the presence of water chemically react with calcium hydroxide liberated on hydration at ordinary temperature to form compounds possessing cementitious properties. In our experiment we are using micro silica an artificial pozzolans. We are partially replacing cement with silica fume by adding 0%, 5%, 7.5%, 10%, 12.5% by weight of cement in concrete and comparing the compressive strength of normal concrete with silica fume replaced concrete. This study has shown that between 5 to 10% replacement level of cement by silica fume in concrete will develop strength sufficient for construction purposes. Its use will lead to a reduction in cement quantity required for construction purposes and hence sustainability in the construction industry as well as aid economic construction.*

Keywords: Silica fume, compressive strength, slump, High strength concrete, high performance concrete. Supplementary cementing materials (SCM), Ground granulated blast furnace slag (GGBS), conventional CEM I concrete (Normal concrete)

1. Introduction

In order to reduce the green gas emission. Industrial wastes, such as silica fume, blast furnace slag, fly ash are being used as supplementary cement replacement materials and recently, agricultural wastes are also being used as pozzolanic materials in concrete. When pozzolanic materials are incorporated to concrete, the silica present in these materials react with the calcium hydroxide released during the hydration of cement and forms additional calcium silicate hydrate (C – S–H), which improve durability and the mechanical properties of concrete. Mineral admixture are widely used in concrete for various reasons especially for reducing the amount of cement required for making concrete which shows to a reduction in construction cost. Moreover most pozzolanic materials are by product materials. The use of these materials shows the reduction in waste, freeing up valuable land, save in energy consumption to produce cement and save the environment. Out of these supplementary cementitious materials, silica fume is the one of the waste materials that is being produced in tones of industrial waste per year in our country. Silica fume is a very fine pozzolanic material. It is a by-product of producing silicon metal or ferrosilicon alloys. One of the most beneficial uses of silica fume is in concrete. Because of its chemical and physical properties; it is a very reactive pozzolanic material. Concrete containing silica fume has very high strength and is very durable.

Silica fume is sold in powder form but is more commonly available in a liquid. Silica fume is used in amounts between 5% and 15% by mass of the total cementitious material. It is used in applications where a high degree of impermeability is needed and in high- strength concrete. Global

consumption of silica fume exceeds 1 million tonnes per annum. Silica fume is generally dark grey to black or off-white in colour and can be supplied as a densified powder or slurry depending on the application and the available handling facilities. To maximise the full strength producing potential of silica fume in concrete it is recommended that it should always be used with a dispersant admixture such as high range water reducing agent (HRWRA). The dosage will depend on the amount of silica fume and the type of admixture used. The dosage of air-entraining admixture to produce a required volume of air in concrete usually increases with the amount of silica fume.

The main field of application is as pozzolanic material for high performance concrete. Silica fume is an ultrafine airborne material with spherical particles less than 1 µm in diameter, the average being about 0.1 µm. This makes it approximately 100 times smaller than the average cement particle. The unit weight, or bulk density, of silica fume depends on the metal from which it is produced. Its unit weight usually varies from 130 to 430 kg/m³. The specific gravity of silica fume is generally in the range of 2.20 to 2.5. Portland cement has a relative density of about 3.15 In order to measure the specific surface area of silica fume a specialized test called the "BET method" or nitrogen adsorption method must be used. Based on this test the specific surface of silica fume typically ranges from 15,000 to 30,000 m²/kg. Silica fume increase durability, toughness and it give very low permeability to chloride and water intrusion in the concrete.

Chemical admixtures can be used with silica fume in the same way as for conventional concretes. Silica fume is

normally used with a super-plasticiser (High range water reducer).

2. Workability/Consistence

Fresh concrete containing silica fume is more cohesive and less prone to segregation than concrete without silica fume. Experience has shown that it is necessary to increase the initial slump of concrete with silica fume by approximately 50mm above than required for conventional CEM I concrete to maintain the same apparent workability. Silica fume addition has been used to assist in pumping long distances, especially vertically. Concrete was pumped in a single operation to a height of 601 metres at the Burj Khalifa project in Dubai; so far the world's tallest building.

Setting time

Unlike other SCM's such as slag and fly ash, silica fume does not significantly affect setting time.

Water demand

Silica fume can be expected to produce an increased water demand, which is normally countered by the use of admixtures. The water demand of concrete containing silica fume increases with increasing amounts of silica fume. This increase is caused primarily by the high surface area of the silica fume. To achieve a maximum improvement in strength and durability, silica-fume concrete should contain a high-range water reducing admixture.

Bleeding

Concrete containing silica fume shows significantly reduced bleeding. As silica fume dosage is increased, bleeding will be reduced. This effect is caused primarily by the high surface area of the silica fume to be wetted; there is very little free water left in the mixture for bleeding, Jahren points out that because of the reduced bleeding, care should be taken to prevent early moisture loss from freshly placed silica-fume concrete, particularly under conditions that promote rapid surface drying.

Heat of hydration

Silica fume has effectively a similar heat of hydration to CEM I. A reduction in the early age temperature rise can reduce the risk of early-age thermal cracking, Early-age thermal crack control in concrete. However a slower release of heat can reduce the initial rate of strength gain. This may necessitate longer periods before striking formwork and/or removal of props especially when casting thin, exposed sections in winter conditions in cooler climates. It also points out that silica fume, when used with a high range water reducing admixture, can achieve equivalent strength with a reduced binder content and thereby lower heat output.

Sensitivity to curing

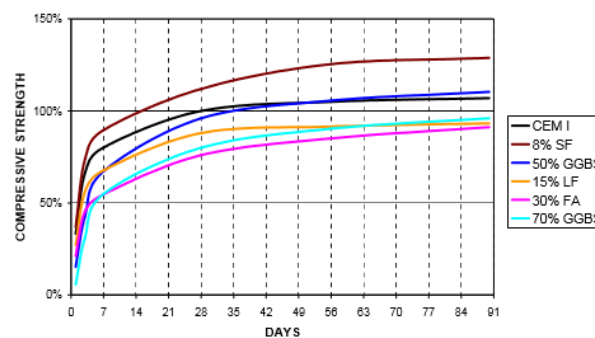
Concrete stiffens and hardens through the hydration reaction between cement and water. Strength and microstructure, which depend on the degree of hydration, can be adversely affected if concrete is allowed to dry out at early ages and hydration is prematurely arrested. The layer close to the surface seems to be the most sensitive, as evidenced by the large effect of curing on abrasion-resistance. At greater depth, in the region approaching the level of the reinforcing

steel, the effect of curing appears to be less critical. With silica fume, the concrete may contain very little free water and with significantly reduced bleed there needs to be extra emphasis on curing so that the surface layer retains the water needed for development of the properties of the concrete. To obtain the full benefits of silica fume concrete, proper curing procedures must be followed. Because concrete containing silica fume shows significantly reduced bleed (as dosage is increased)

3. Effect on Concrete Strength

Strength Development

strength development at a fixed w/c ratio, where concretes containing fly ash, limestone fines or high-replacement GGBS generally have lower 28-day strength than CEM I while silica fume can give increased 28-day strength.



Above figure shows indicative longer-term strength development, where for concretes required to achieve specified 28-day strength, those containing GGBS, fly ash and silica fume generally show increased ultimate strengths.

Concrete made with silica fume follows the conventional relationship between compressive strength and w/c but strength is increased at a given w/c ratio when silica fume is used. High early compressive strength (in excess of 25N/mm^2 at 24 hours) can be achieved. With proper concrete design, very high 28-day strengths can be produced, using normal ready-mixed concrete plants. In the USA and Asia $100\text{--}130\text{N/mm}^2$ concretes are used in tall buildings. Cementitious contents are generally $> 400\text{ kg/m}^3$ and w/c in the range 0.30 to 0.40. An example in South East Asia is the new 79 floor East Island Centre in Hong Kong where the volume of concrete was reduced by 15% through the use of Grade 100 MPa self-compacting concrete. Not only were there significant sustainability benefits but also the client benefited commercially through the additional floor space opened up for rental in this expensive part of Hong Kong.

4. Effect on Concrete Durability

Permeability

Silica fume can produce very large reductions in water permeability of up to one order magnitude or more, depending on the mix design and dosage of silica fume. The reduction in the size of capillary pores increases the probability of transforming continuous pores into discontinuous one. Because capillary porosity is related to permeability, the permeability to liquids and vapours is thus reduced by silica fume addition.

Protection to embedded steel (carbonation)

Steel embedded in concrete is protected against corrosion by the alkalinity of the cement paste. Despite any reduction in calcium hydroxide, resulting from the incorporation of silica fume, the pH of the cement paste remains at an adequately high level to protect steel. Carbonation can reduce the alkalinity and protection to the steel. Silica fume concrete tends to show greater carbonation than CEM I mixes of equivalent 28 day strength.

Protection to embedded steel (chlorides)

If chloride permeates the concrete to the depth of the reinforcement it can initiate corrosion of the steel. Concrete made with silica fume is generally substantially more resistant to chloride diffusion than CEM I concrete and for reinforced concrete structures exposed to chlorides; its use will give enhanced durability.

Sulphate resistance

Sulphate attack of concrete occurs through both chemical and physical processes. Two main reactions are involved, these being the reaction of sulphate ions with hydrated calcium aluminates forming ettringite, and the combination of sulphate ions with free calcium hydroxide forming gypsum. The first reaction is of more practical significance. Considerable increases in volume result from both reactions causing expansion and disruption of the hardened concrete. Thaumasite is a calcium silicate sulfo-carbonate hydrate, which forms at temperatures below 15°C by a reaction between cement paste hydrates, carbonate and sulphate ions. Its formation reduces the cement paste to a soft mulch. Unfortunately, conventional Sulfate Resisting Portland Cement offers no protection against the Thaumasite form of sulphate attack. GGBS, fly ash and silica fume can substantially increase the resistance to both forms of sulphate attack compared with CEM I concrete.

Resistance to acids

All types of cement are susceptible to attack by acids and, in highly acid solutions (e.g. pH less than 3.5), dissolution of the cement matrix and subsequent loss of integrity of concrete will occur. Luther suggests that silica fume will increase the resistance of concrete to dilute acids and chemical attack through reduced permeability and through reduced content of calcium hydroxide. Silica- fume concrete is not completely impervious to all aggressive chemicals, especially in the case of concentrated acid attack on the surface; however, research and field performance show that at a low w/c, silica-fume concrete can be used effectively to prevent significant damage by many types of chemical attack including sewage and silica fume concrete has been specified for use in sewer and outfall pipes in many countries.

Freeze-thaw resistance (for cold weather climates)

Numerous investigators have shown that it is possible to produce freeze thaw resistant, air-entrained concrete containing silica fume. In these studies satisfactory freeze thaw durability factors were obtained at w/c ratios up to 0.60. Yamato et al and Malhotra et al suggest that, for freeze thaw resistance, the silica fume content should be limited to a maximum of 15%. Silica-fume concrete without entrained

air is conflicting and recommends that silica fume concrete should be air entrained where adequate resistance to freezing- and-thawing conditions is required.

Alkali-silica reaction

Alkali-silica reaction (ASR) is a reaction between the hydroxyl ions in the pore water within concrete and certain forms of silica, which occur as part of some aggregates. The product of the alkali-silica reaction is a gel which imbibes pore fluid and expands; in some instances this expansion induces internal stress in the concrete of such magnitude that extensive macro-cracking of the concrete occurs. The damage occurs in parts of the concrete structure exposed to moisture. Silica fume can reduce the risk of damage due to ASR.

Resistance to fire

There is no evidence to suggest that the type of cementitious material will have a large effect on the resistance to fire. In some cases of extremely low permeability concrete, explosive spalling has been reported.

A number of researchers have demonstrated that the fire performance of silica-fume concrete is little different from that of conventional concrete, see for example Jensen and Aarup and Dumuolin and Behloul. Properties such as thermal conductivity and specific heat do not change significantly, and there is evidence that properties during the fire and residual properties are actually better for silica-fume concrete.

5. Effect on Concrete's Physical Properties

Colour

Although the curing time and formwork type can have some effect, the colour of concrete is principally determined by the colour of the cementitious material. Although 'white cements' are available at a price, CEM I is normally a shade of grey. Most silica fumes range from light to dark grey. Because SiO₂ is colourless, the colour is determined by the non-silica components, which typically include carbon and iron oxide. In general, the higher the carbon content, the darker the silica fume. The carbon content of silica fume is affected by many factors relating to the manufacturing process, such as: use of wood chips versus coal, wood chip composition, furnace temperature, furnace exhaust temperature, and the type of product (metal alloy) being produced. Almost white coloured silica fume is available for use in architectural concrete.

Elastic Modulus

GGBS, fly ash or silica fume usually increase the ultimate modulus, but the magnitude of the increase is generally not significant in terms of design.

Sellevoid et al found that the dynamic modulus of elasticity increases with increasing silica-fume content in pastes. Helland, Hoff and Einstabland concluded that the stress-strain behaviour of silica- fume concrete was similar to that of concrete without silica fume. Several other researchers have reported that the static modulus of elasticity of silica-fume concrete is apparently similar to that of concrete without silica fume of similar strength.

Creep

The creep of silica-fume concrete should be no higher than that of concrete of equal strength class without silica fumes. Where the load is applied at an age less than 28-days, the lower early-strengths of GGBS or fly ash concretes may result in increased creep. Wolsiefer examined concretes loaded from both 12 hours and 28 days up to 4 months. He found that the silica fume concretes exhibit less creep than would have been expected from control concrete of equivalent strength. Penttala studied high strength concretes with 10% silica fume addition and found that the creep was 20% less than theoretical predictions.

Tensile Strain Capacity Concrete Society Digest 2, Mass concrete suggests that concrete containing GGBS or fly ash might exhibit marginally more brittle failure characteristics, with the tensile strain capacity being slightly lower than for a similar strength class CEM I concrete. However data on the effects of cementitious materials on the tensile strain capacity of concrete is very limited.

Drying Shrinkage

10% silica fume as replacement for CEM I reduced the long-term drying shrinkage of the concrete after 28 days; however, it increased the early-age shrinkage after an initial curing of 7 days in lime water.

Micro filler effect

Silica Fume is an extremely fine material, with an average diameter 100 times finer than cement. At a typical dosage of 8% by weight of cement, approximately 100,000 particles for each grain of cement will fill the water spaces in fresh concrete. This eliminates bleed and the weak transition zone between aggregate and paste found in normal concrete. This micro filler effect greatly reduces permeability and improves paste-to aggregate bond in SF concrete compared to conventional concrete

6. Experimental Investigation

Mix design

Concrete mix design is the appropriate selection and proportioning of constituents to produce a concrete with pre-defined characteristics in the fresh and hardened states. In general, concrete mixes are designed in order to achieve a defined workability, strength and durability.

The selection and proportioning of materials depend on:

- The structural requirements of the concrete
- The environment to which the structure will be exposed
- The job site conditions, especially the methods of concrete production, transport, placement, compaction and finishing
- The characteristics of the available raw materials

The mix proportioning for a concrete of M 50 Grade with W/C ratio 0.38

Selection of water content

From table 2 (IS 10262:2009)

Maximum water content for 20mm aggregate = 186 litre (for 25 to 50mm slump range)

The mix proportion (for M50) grade of concrete is

Cement : F.A : C.A
 1 : 1.57 : 2.74

The casted cubes were tested for their compressive strength for 7, 14 & 28 days and the results are tabulated as follows.

% Replacement of cement by silica fume	Cement (in Kg/m ³)	Silica Fume (in Kg/m ³)	Fine aggregate (in Kg/m ³)	Coarse aggregate (in Kg/m ³)
0%	1.373	0.000	2.27	3.974
5%	1.373	0.072	2.27	3.974
7.5%	1.373	0.108	2.27	3.974
10%	1.30	0.1445	2.27	3.974
12.5%	1.264	0.1806	2.27	3.974

Test results on Fresh concrete:-

The slump value is a measure indicating the Workability of cement concrete. Higher the slump value greater is workability. It gives an idea of water content needed for concrete to be used for different works. A concrete is said to be workable if it can be easily mixed, placed, compacted and finished. The obtained results are tabulated as follows:

Percentages of Silica Fume	Slump value obtained (mm)
0%	95
5%	82
7.5%	77
10%	71
12.5%	68

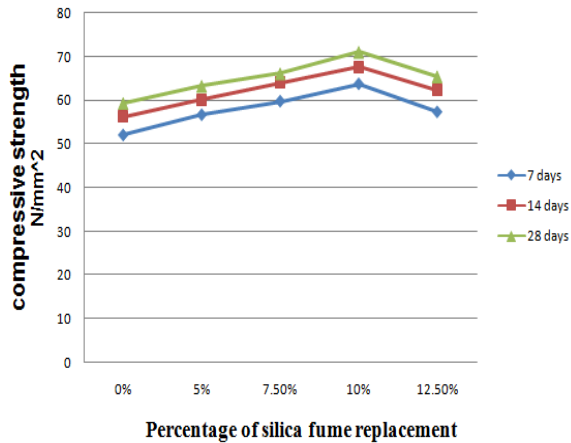
Tests on Hardened Concrete

Concrete cubes of sizes 150mmx150mmx150mm were prepared with percentage replacement of cement with silica fume and are cured under normal conditions as IS code and were tested for 7,14,28 days for determining compressive strength .

% Replacement of cement by silica fume	Age of Curing of Cubes	Compressive strength (Mpa)
0	7	52.07
	14	56.29
	28	59.34
5	7	56.70
	14	60.17
	28	63.30
7.5	7	59.79
	14	64.10
	28	66.14
10	7	63.74
	14	67.65
	28	71.07
12.5	7	57.36
	14	62.36
	28	64.73

Comparison of Strengths of Normal and Silica Fume concretes:-

[7] 1. Silica fume manual by Oriental Trexim Pvt. Ltd. (2003)



From the graph studies a comparative conclusion can be drawn from the strengths of normal and silica fume concretes and we can know which one does gives high strength.

Result

The following graph show that the maximum strength achieved is at 10% silica fume contain concrete The results indicate that for the concrete mix and silica fume used in this study, the optimum replacement level of silica fume is about 10%.

7. Conclusion

- 1) Its shows that at 10% of silica replaced concrete has given more strength when compare to the normal concrete.
- 2) Silica fume also decrease the voids in concrete.
- 3) The incorporation of silica fume in concrete has a marginal influence on the density of concrete.
- 4) The results indicate that for the concrete mix and silica fume used in this study, the optimum replacement level of silica fume is about 10%.

References

- [1] Verma Ajay, Chandak Rajeev and Yadav R.K. "Effect of micro silica on the strength of concrete with ordinary Portland cement" Research journal of Engineering Science ISSN 2278-9472 vol.1(3), 1-4, sept (2012).
- [2] Dilip Kumar Singha Roy "Effect of Partial Replacement of Cement by Silica Fume on Hardened Concrete". International journal of engineering Technology and Advanced Engineering (ISSN 2250-2459, volume 2, issue 8, August 2012).
- [3] T. Shanmugapriya, Dr. R. N. Uma "Experimental Investigation on silica Fume as partial replacement of Cement in High Performance Concrete". (IJES) 2013.
- [4] IS 456-2000, "Indian Standard Code of Practice for plain and reinforced concrete" Fourth revision, BIS, New Delhi.
- [5] IS 383-1970,
- [6] IS: 10262-1982, "Recommended guidelines for concrete mix design, "BIS, New Delhi.