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# A study on the Mix Design parameters of High Strength Concrete using Iso-Strength lines

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***Abstract***: *Concrete production exists around the globe and is one of the leading construction material, essentially man made stone that has become a most versatile and universally recognised tool to build with. Concrete is a widely used structural material which essentially consists of a binder and a mineral filler. It has the unique distinction of being the only construction material which is manufactured actually on the site, whereas other materials are merely shaped and fabricated and eventually assembled at site. Ever since the time of Romans, there has been a continuous effort by the research workers in the field of cement and concrete technology to produce better quality cement resulting in concretes of overall improved quality. The introduction of reinforced concrete as an alternative to steel construction, in the beginning of 20th century, necessitated the developement and use of low and medium strength concretes. In keeping with the demands of the nuclear age, high density concrete has been successfully used for the radiation shielding of highly active nuclear reactors. Considerable progress has been achieved in the design and use of structural light weight concretes, which have the dual advantage of reduced density coupled with increased thermal insulation. With the present state of knowledge in the field of concrete mix design, it is possible to select and design concrete capable of resisting heat, sea water, frost and chemical attack arising out of industrial effluents. High strength and high performance concrete are being widely used throughout the globe and in the production of these concretes it is necessary to reduce the water/binder ratio with the subsequent increase in the binder content. High strength concrete refers to good abrasion, impact and cavitation resistance. The deterioration and premature failure of concrete structures such as marine structures, concrete bridge deck etc. has lead to the developement of high performance concrete. The high performance concrete is defined as the high-tech concrete whose properties have been altered to satisfy specific engineering properties such as high workability, very high strength, high toughness and high durability to severe exposure condition. Nowadays silica fume is almost invariably used in the production of High Performance Concretes. In future, high range water reducing admixtures (Superplasticizers) will open up new possibilities for the use of such material as partial replacement of cement to produce and develop high strength concrete, as some of them are much finer than cement. The existing literature is rich in information on silica fume concrete and after performing a detail review of the research papers published over the last two decades, the objective of the present study was framed.*
***Keywords:*** *Compacting factor, fresh concrete properties, silica fume, water binder ratio, workability.*

## I. Introduction

Condensed silica fume is generally used as an admixture mixed with ordinary portland cement in the dry state or as suspension in water which contains a water reducing admixture. Hence water-cementatious ratio has to be properly maintained to achieve suitable desired workability and strength. Silica fume greater than 5 percent by weight of cement requires the use of superplasticizing or water reducing admixtures to achieve high strength and durability. Two basic considerations that have been considered for design are strength and workability. All the mixes had slump between 100 to 230 mm and strength between 40 to 76 Mpa at 28 days. In the following sections mix design steps have been produced.

## II. Mix Design

According to Shah and Ahmad (1994) for proportioning of high strength concretes, mostly purely empirical procedures based on trial mixtures are used and the trial mix approach is best for proportioning high strength concretes. Any mix proportioning method for High Strength Concrete is yet to be universally accepted. The Indian Standard- "Recommended Guidelines for Concrete Mix Design"(IS-10262) is meant for the design of low to medium strength concretes but does not include the design of concrete mixes when pozzolans and admixtures arre used. Therefore for arriving at the reference mix, the basic principles on which high strength concrete mix should be based were considered and the proportions of a number of mixes incorporating silica fume as reported in the literature were reviewed. Since the strength of silica fume concretes depend on a host of parameters, in order to study the effect of silica fume only, the others were to be kept constant. Hence the mix proportion as well as the dosage of SP were to be kept constant as in the reference mix. For High Strength Concrete the content of cementitious material is higher ranging from 500-650 kg/m$^3$ (Shah and Ahmad,1994). For the present investigation the binder content will be maintained at 525 kg/m$^3$. Coarse aggregate and fine aggregate were maintained at a ratio of 60:40 for obtaining the maximum packing density. The detailed mix proportion is presented in the table 01:

| Mixes | W/B | Cement (Kg/m$^3$) | Silica Fume | | Aggregates (Kg/m$^3$) | | Water (Kg/m$^3$) |
|---|---|---|---|---|---|---|---|
| | | | % | (Kg/m$^3$) | Fine | Coarse | |
| SFC 01 | 0.30 | 525 | 0 | 0 | 724.457 | 1086.686 | 157.5 |
| SFC 02 | | 498.75 | 5 | 26.25 | 720.598 | 1080.897 | |
| SFC 03 | | 472.5 | 10 | 52.5 | 716.739 | 1075.108 | |
| SFC 04 | | 446.25 | 15 | 78.75 | 712.98 | 1069.48 | |
| SFC 05 | 0.34 | 525 | 0 | 0 | 701.945 | 1052.920 | 178.5 |
| SFC 06 | | 498.75 | 5 | 26.25 | 698.194 | 1047.290 | |
| SFC 07 | | 472.5 | 10 | 52.5 | 694.227 | 1041.340 | |
| SFC 08 | | 446.25 | 15 | 78.75 | 690.368 | 1035.552 | |
| SFC 09 | 0.38 | 525 | 0 | 0 | 679.648 | 1019.472 | 199.5 |
| SFC 10 | | 498.75 | 5 | 26.25 | 675.574 | 1013.361 | |
| SFC 11 | | 472.5 | 10 | 52.5 | 672.144 | 1008.216 | |
| SFC 12 | | 446.25 | 15 | 78.75 | 667.963 | 1001.944 | |
| SFC 13 | 0.42 | 525 | 0 | 0 | 656.921 | 985.382 | 220.5 |
| SFC 14 | | 498.75 | 5 | 26.25 | 653.062 | 979.593 | |
| SFC 15 | | 472.5 | 10 | 52.5 | 649.203 | 973.804 | |
| SFC 16 | | 446.25 | 15 | 78.75 | 645.344 | 968.016 | |

**Table 01: Detailed Mix Proportion**

## III. Considerations Of Workability

A properly designed mix must be capable of being placed and compacted properly with the equipment available. Segregation and bleeding should be avoided. As per IS 10262 : 2009, water content in the conventional concrete mix (containing Portland cement) is influenced by a number of factors such as aggregate characteristics, degree of workability desired, water-cement ratio, cement and other supplementary materials type and content and amount of chemical admixtures. It has also been categorically mentioned that a reduction in water cement ratio and slump will reduce the water demand while increased cement content, slump and a decrease in the proportion of coarse to fine aggregate will increase the water demand. Slump values can be increased simply by adding more cement and water or by increasing water content alone (Neville, 1996). Hence it may be inferred that for a given aggregate characteristics, workability of concrete depends primarily on the water content which again depends on the binder contents and w/cm ratios. For the present investigation type of aggregates, characteristics of cement and fly ash and coarse to fine aggregate ratio have been kept constant in all the mixes.

| Mix ID: | W/B Ratio: | Slump: (mm) | Compacting Factor: | Density: (Kg/m$^3$) |
|---|---|---|---|---|
| AE 0 | 0.30 | 210 | 0.99 | 2592 |
| AE 05 | | 190 | 0.98 | 2548 |
| AE 10 | | 150 | 0.96 | 2500 |
| AE 15 | | 100 | 0.91 | 2459 |
| AF 0 | 0.34 | 200 | 0.99 | 2550 |
| AF 05 | | 170 | 0.98 | 2520 |
| AF 10 | | 150 | 0.95 | 2480 |
| AF 15 | | 110 | 0.90 | 2450 |
| AG 0 | 0.38 | 210 | 0.99 | 2540 |
| AG 05 | | 190 | 0.98 | 2500 |
| AG 10 | | 160 | 0.96 | 2458 |
| AG 15 | | 120 | 0.93 | 2430 |
| AH 0 | 0.42 | 230 | 0.99 | 2520 |
| AH 05 | | 200 | 0.98 | 2480 |
| AH 10 | | 180 | 0.96 | 2450 |
| AH 15 | | 150 | 0.94 | 2420 |

**Table 02: Detailed Fresh Concrete Parameters:**

For the present investigation slump values have been measured over a wide range of silica fume replacement percentages and water binder ratios. Slump values have varied between 150 to 230 mm i.e. flowing concretes due to minimum variations in mixing water contents. Slump test is one of the simplest and easiest ways of measuring workability of concrete. It is very easy to perform as the equipment required is very simple and easily available.The Indian Standard code of practice for plain and reinforced concrete (IS: 456) has prescribed slump tests for quality control of fresh concrete at site due to its ease and simplicity. Since the test is very simple it is a bit crude and numerical values can vary considerably for the same concrete from person to person. From the results of present investigation on silica fume concrete with replacement levels of 0-15%, approximate estimates of slump values may be obtained for different water binder ratios and binder contents.

Regression analysis has been performed using the present data base. After analysis, a linear graphical plot has been drawn.

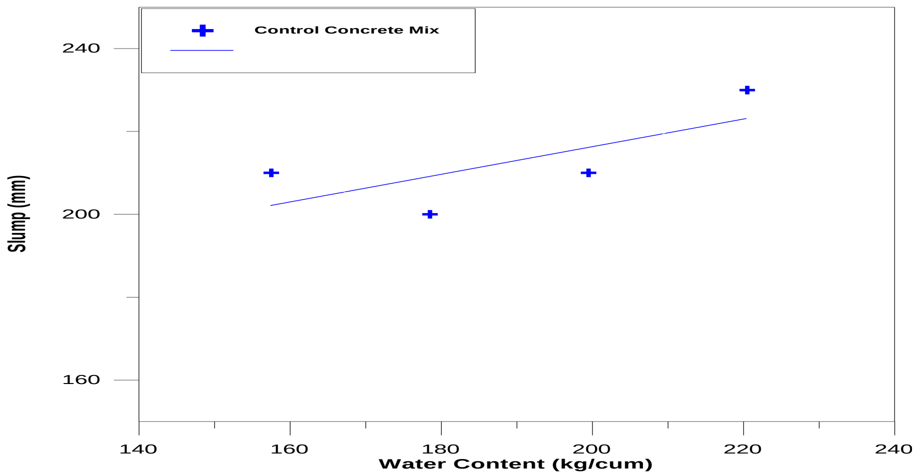


**Figure 01: Relationship between Slump of control mix and water content**

From the figure, it is clear that for the control mixes, 200 to 220 mm slump could be achieved at a water content range of 170 to 210 kg/cum. The results of the slump values at 5% replacement level indicate a marginally lower slump value with respect to control design mixes, i.e. 180-200 mm slump can be achieved at a water/cement ratio range of 160-210 kg/m$^3$. Similarly at 10% silica fume replacement percentage, slump in the range of 150-170mm corresponding to the same water content range as in control mix, i.e.160-210 kg/m$^3$. But at 15% silica fume replacement percentage, the workability of the concrete decreases considerably. For the water content range of 160-210 kg/m$^3$, slump values in the range of 100-140 mm is obtained.

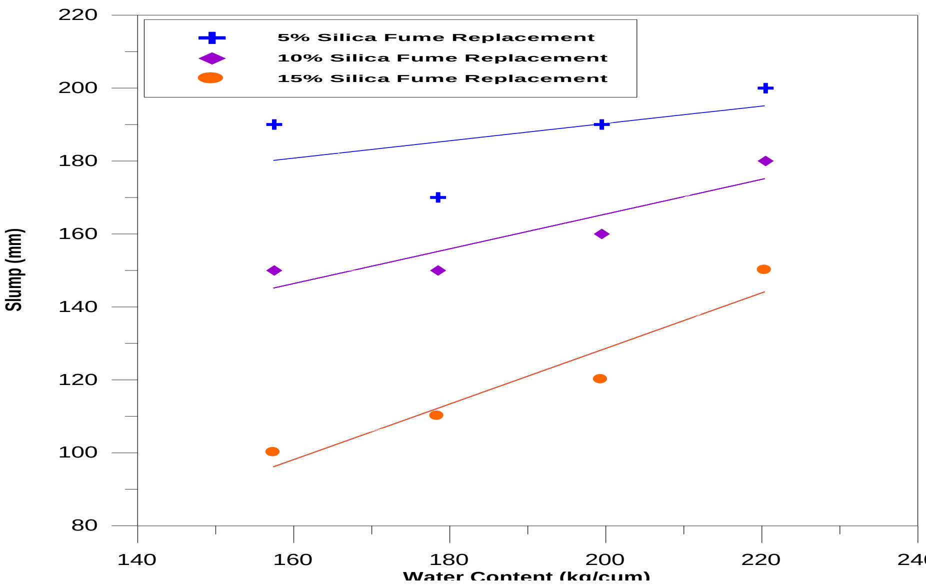


**Figure 02: Relationship between Slump of silica fume mixes and water content**

## IV. Considerations Of Strength

Compressive strength represents the overall quality of any concrete. Hence a concrete that is to be designed should satisfy a minimum compressive strength at the end of a specified age of curing. It is well accepted that strength depends on a host of parameters. In a Portland cement only concrete, strength is primarily a function of w/c ratio provided that it is fully compacted (Abrams law). Mix design methods of concrete with admixtures are mostly empirical and based on trial mixes. In the following paragraph an attempt has been made to develop some design charts for compressive strength of concrete incorporating silica fume. Concrete mixes are designed for a specified compressive strength at a specified age. For the present work, 28 and 90 day strengths have been considered. Strength of concrete at 28 and 90 days can be predicted using the following equations:

***For 28 days —***

**LN S(28)=4.989-2.897(w/cm)+0.012(sf%)**

***For 90 days —***

**LN S(90)=4.850-2.209(w/cm)+0.009(sf%)**

| W/B Ratio | Binder ($Kg/m^3$) | Silica Fume % | Compressive Strength (MPa) | | |
|---|---|---|---|---|---|
| | | | 7 Days | 28 Days | 90 Days |
| 0.30 | 525 | 0 | 43 | 60 | 63 |
| | | 5 | 46 | 66 | 70 |
| | | 10 | 54 | 76 | 81 |
| | | 15 | 45 | 65 | 68 |
| 0.34 | 525 | 0 | 38 | 53 | 60 |
| | | 5 | 40 | 62 | 66 |
| | | 10 | 48 | 68 | 71 |
| | | 15 | 40 | 61 | 65 |
| 0.38 | 525 | 0 | 32 | 45 | 53 |
| | | 5 | 35 | 53 | 58 |
| | | 10 | 38 | 60 | 64 |
| | | 15 | 35 | 58 | 62 |
| 0.42 | 525 | 0 | 28 | 42 | 48 |
| | | 5 | 33 | 46 | 53 |
| | | 10 | 37 | 52 | 59 |
| | | 15 | 36 | 49 | 57 |

**Table 03: Detailed Compressive Strength At 7, 28 and 90 days:**

| Ranges of w/cm and silica fume % | | | | Suggested Compressive strength values for 28 days (MPa) |
|---|---|---|---|---|
| w/cm | SilicaFume (%) | w/cm | Silica Fume (%) | |
| 0.40 | 4% | 0.42 | 9% | 45 |
| 0.38 | 4% | 0.40 | 8% | 50 |
| 0.34 | 2% | 0.36 | 6% | 55 |
| 0.32 | 4% | 0.34 | 9% | 60 |
| 0.32 | 9% | 0.34 | 14% | 65 |

**Table 04: Suggested ranges of w/cm ratio and silica fume percentages for different compressive strength at 28 days:**

Where, w/cm= water to binder ratio and sf = Silica Fume Replacement percentages. Using these equations, iso–strength lines representing different combinations of water binder ratios (w/cm) and silica fume replacements (sf%) have been plotted. If the silica fume replacement is initially fixed depending on the project requirements, an approximate value of w/cm may be considered to meet the target strength.

| Ranges of w/cm and silica fume % | | | | Suggested Compressive strength values for 90 days (MPa) |
|---|---|---|---|---|
| w/cm | SilicaFume (%) | w/cm | Silica Fume (%) | |
| 0.40 | 4% | 0.42 | 9% | 55 |
| 0.34 | 0% | 0.36 | 5% | 60 |
| 0.32 | 4% | 0.34 | 8% | 65 |
| 0.30 | 7% | 0.32 | 11% | 70 |

**Table 05: Suggested ranges of w/cm ratio and silica fume percentages for different compressive strength at 90 days:**

In this connection a graphical software D-Plot has been used. Using these plots, strength of silica fume concretes can be predicted for different replacement percentages of silica fume. The suggested ranges of compressive strength of high strength silica fume concretes for different silica fume replacement percentages calculated using the iso-strength plots and are presented in Tables. The table gives an idea about the strengths expected to be obtained at two extreme values of w/cm for the silica fume replacement ranging from 5-15%.

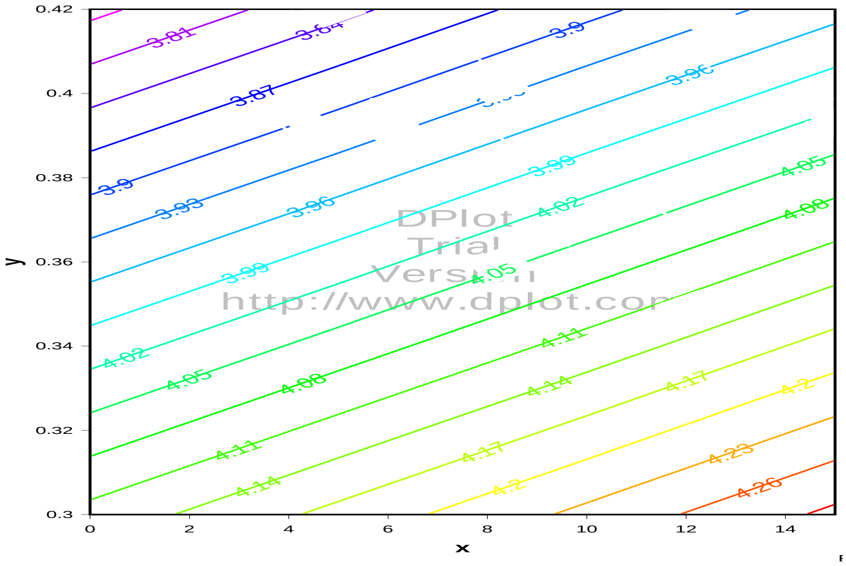


**Figure 03: Design chart for log (28 day Compressive strength) in the form of Iso-strength line:**

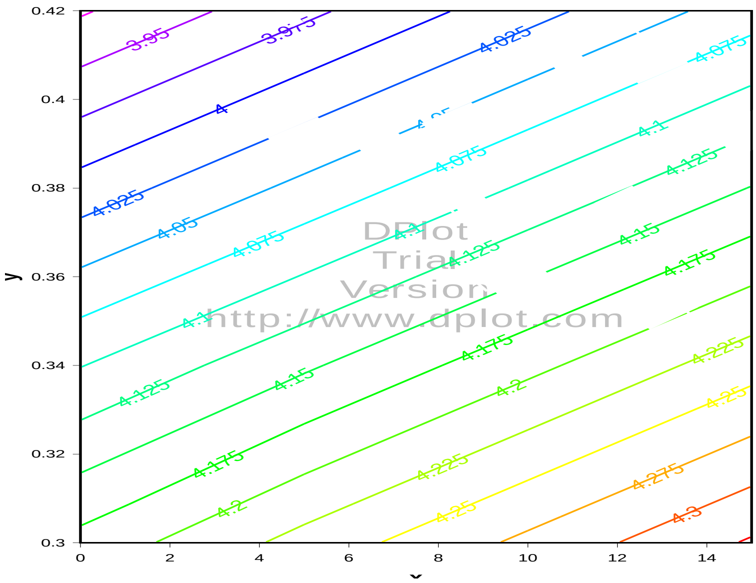


**Figure 04: Design chart for log (90 day Compressive strength) in the form of Iso-strength lines:**

## V. Findings From The Study:

The findings from the present study may be summarized as follows —

1) Slump values of silica fume concrete have been presented graphically. Using this plot the amounts of water required by a silica fume concrete for achieving a specified slump can be determined using some assumptions.
2) Using the iso-strength plots, for different silica fume replacement percentages and water to binder ratio, suggested ranges of strength of concrete incorporating silica fume have been presented in a table.
3) The methodology presented herein can serve as a useful tool to the designers for selecting some key parameters while proportioning silica fume concrete instead of merely assuming some values of the same.

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