# Influence of Silica Fume on the Properties of Self Compacting Concrete

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***Abstract*—**A self-compacting concrete (SCC) is the one that can be placed in the form and can go through obstructions by its own weight and without the need of vibration. Since its first development in Japan in 1988, SCC has gained wider acceptance in Japan, Europe and USA due to its inherent distinct advantages. Although there are visible signs of its gradual acceptance in the North Africa through its limited use in construction, Libya has yet to explore the feasibility and applicability of SCC in new construction. The contributing factors to this reluctance appear to be lack of any supportive evidence of its suitability with local aggregates and the harsh environmental conditions. The primary aim of this study is to explore the feasibility of using SCC made with local aggregates of Eastern Province of Libya by examining its basic properties characteristics. This research consists of: (i) Development of a suitable mix for SCC such as the effect of water to cement ratio, limestone and silica fume that would satisfy the requirements of the plastic state; (ii) Casting of concrete samples and testing them for compressive strength and unit weight. Local aggregates, cement, admixtures and industrial waste materials were used in this research.

The significance of this research lies in its attempt to provide some performance data of SCC made in the Eastern Province of Libya so as to draw attention to the possible use of SCC.

***Keywords*—**Silica fume, self compacting concrete, workability, coarse and fine aggregate.

## I. Introduction

DEVELOPMENT of self- compacting concrete (SCC) is a desirable achievement in the construction industry in order to overcome problems associated with cast-in-place concrete. Self-compacting concrete is not affected by the skills of workers, the shape and amount of reinforcing bars or arrangement of a structure, and due to its high –fluidity and resistance to segregation it can be pumped longer distances [1].

The concept of self-compacting concrete was proposed in 1986 [2], but the prototype was first developed in 1988 in Japan [3]. Self-compacting concrete was developed at that time to improve the durability of concrete structures. Self-compacting concrete is cast so that no additional inner or outer vibration is necessary for the compaction. It flows like "honey" and has a very smooth surface level after placing. With regard to its composition, self-compacting concrete consists of the same components as conventionally vibrated concrete, which are cement, aggregates, and water, with the addition of chemical and mineral admixtures in different proportions. Usually, the chemical admixtures used are high-range water reducer (super plasticizers) and viscosity-modifying agents. Mineral admixtures are used as an extra fine material, besides cement, and in some cases, they replace cement.

Self-compacting concrete, in principle, is not a new. Special applications such as underwater concreting have always required concrete which, could be placed without need for compaction [1]. In such circumstances vibration was simply impossible. Early self-compacting concretes relied on very high contents of cement paste and, once super plasticizers became available, they were added in the concrete mixes. The mixes require specialized and well –controlled placing methods in order to avoid segregation, and the high contents of cement paste made them prone to shrinkage. The overall costs were very high and application remained very limited. In the early 1990's there was only a limited public knowledge about SCC, mainly in the Japanese language. Simultaneously with the Japanese developments in the SCC area, research and development continued in mix-design and placing of underwater concrete where new admixtures were producing SCC mixes with performance matching that of the Japanese SCC concrete (e.g. University of Paisley/Scotland, University of Sherbrooke / Canada [4].

The motive for development of self-compacting concrete was the problem on durability of concrete structures that arose around 1983 in Japan .Due to a gradual reduction in the number of skilled workers in Japan's construction industry , a similar reduction in the quality of construction work took place .As a result of this fact, one solution for the achievement of durable concrete structures independent of the quality of construction work was the employment of self-compacting concrete, which could be compacted into every corner of a formwork , purely by means of its own weight. Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, were carried out by Ozawa and Maekawa [3] at the University of Tokyo. The main reasons for the employment of self-compacting concrete can be summarized as follows:

1. To shorten construction period.
2. To assure compaction in the structure; especially in confined zones where vibrating compaction is difficult.
3. To eliminate noise due to vibration (effective especially at concrete product plants).

Okamura and Ozawa have proposed a mix proportioning system for SCC [3]. In this system, the coarse aggregate and

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fine aggregate contents are fixed and self-compactibility is to be achieved by adjusting the water /powder ratio and super plasticizer dosage. The coarse aggregate content in concrete is generally fixed at 50 percent of the total solid volume, the fine aggregate content is fixed at 40 percent of the mortar volume and the water /powder ratio is assumed to be 0.9-1.0 by volume depending on the properties of the powder and the super plasticizer dosage. The required water /powder ratio is determined by conducting a number of trials. One of the limitations of SCC is that there is no established mix design procedure yet.

This paper describes a procedure specifically developed to achieve self-compacting concrete. In addition, the test results for acceptance characteristics for self-compacting concrete such as slump flow, J-ring, V-funnel, U-box and L-Box are presented. Further, the strength characteristics in terms of compressive strength for 7-days and 28-days are also presented.

## II. Materials Used

### A. Cement

All types of cement are suitable for SCC. For all mixes in this research, Ordinary Portland Cement Type I meeting (ASTM 150) manufactured by Libyan cement company was used in concrete mixes. Chemical composition and physical properties are as given in Table I.

### B. Limestone

SCC has a graded aggregate and a high volume of limestone as filler (in the range of 0 to 50% of the mass of powder). Limestone has been obtained from Libya quarry. Chemical composition and physical properties of Limestone are given in the Table I.

### C. Silica-fume

Silica-fume, also known as condensed silica fume or micro-silica(ACI 116R), is very fine, non-crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or silica-alloys. Silica-fume obtained from “Sika Company, Libya. Chemical properties of Silica-fume are given in the Table I.

TABLE I
CHEMICAL PROPERTIES OF LIME STONE AND SILICA FUME

| | Compounds Name | Compounds | Percent by Weigh % | | |
|---|---|---|---|---|---|
| | | | cement | lime stone | Silica fume |
| 1 | Calcium Oxide | CaO | 62.70 | 52.35 | 0.17 |
| 2 | Silicon Dioxide | $SiO_2$ | 20.60 | 0.45 | 95 |
| 3 | Aluminum Oxide | $AL_2O_3$ | 4.90 | 0.33 | 0.35 |
| 4 | Magnesium Oxide | MgO | 3.10 | 1.05 | 0.09 |
| 5 | Sulphur Trioxide | $SO_3$ | 2.80 | 0.04 | 0.42 |
| 6 | Ferric Oxide | $Fe_2O_3$ | 2.70 | 0.14 | 0.2 |
| 7 | Potassium Oxide | K2O | 0.8 | 0.02 | 0.51 |
| 8 | Sodium Oxide | Na2O | 0.23 | 0.06 | - |
| 9 | Loss on agent | LOI | - | 45.15 | - |
| Specific Gravity | | | 3.15 | 2.71 | 2.25 |

### D. Aggregates

Locally available natural sand with 4.75 mm maximum size was used as fine aggregate, having specific gravity, fineness modulus and absorption capacity as given in Table II and crushed stone with 19 mm maximum size having specific gravity, water absorption ,unit weight, impact value, crushing value and angularity number as given in Table III was used as coarse aggregate. Both fine aggregate and coarse aggregate conformed to Britches and ASTM Standard Specifications.

### E. Admixtures

A viscocrete 5400 based super-plasticizer complying with ASTM C- 494, Type G and F, was used.

## III. Test Methods

Self- Compacting Concrete is characterized by filling ability, passing ability and resistance to segregation. Many different methods have been developed to characterize the properties of SCC. No single method has been found until date, which characterizes all the relevant workability aspects, and hence, each mix has been tested by more than one test method for the different workability parameters. Typical acceptance criteria for SCC with a maximum aggregate size of up to 20 mm are presented in Table IV.

TABLE II
FINE AGGREGATE PROPERTIES

| Property | Test Procedure | Value |
|---|---|---|
| Specific gravity | ASTM C128 | 2.58 |
| Absorption capacity | ASTM C128 | 0.4% |
| Fineness Modulus | ASTM C 33 | 2.72 |

TABLE III
COARSE AGGREGATE PROPERTIES

| Property | Test Procedure | Value |
|---|---|---|
| Specific gravity | ASTM C 127 | 2.56 |
| Water Absorption | ASTM C 127 | 2.15% |
| Bulk Density | ASTM C 29 / 29M | 1419..45 |
| Angularity Number | BS 812 : Part 1 | 6.1 |
| Impact Value | BS 812 : Part 3 | 24.13% |
| Crushing Value | BS 812 : Part 3 | 29.3 % |

TABLE IV
ACCEPTANCE CRITERIA FOR SCC [5]

| Methods | Units | Min. | Max. |
|---|---|---|---|
| Slump flow by Abram's cone | mm | 650 | 800 |
| T50cm Slump flow | sec | 2 | 5 |
| J-ring | mm | 0 | 10 |
| V-funnel | sec | 6 | 12 |
| Time increase, V-funnel at T5 min | sec | 0 | +3 |
| L-box (h2/h1) | - | 0.8 | 1 |
| U-box (h2-h1) | mm | 0 | 30 |

## IV. MIXING PROCEDURES

All Concrete batches were prepared in rotating drum mixer. First, the aggregates are introduced and then one-half of the mixing water was added and rotated for approximate two minutes. Next, the cement, most manufacturers recommend at least 5 minutes mixing upon final introduction of admixtures. Once, the mix was determined to have sufficient visual attributes of SCC, the rheological tests were performed in quick succession. Typically, the order of testing employed was as follows:

1. U-box (height of concrete in each compartment)
2. V-funnel (time to empty).
3. L-Box (T20, T40 and heights at 20 and 40cm).
4. Flow Test.
5. Flow Test.
6. Density (Unit weight).
7. Ring test.
8. Air Determination (using pressure meter).
9. Casting of Specimens

After the flow test was conducted, concrete's visual stability index (VSI) was determined. Criteria used for VSI rating is described in Table V.

## V. EXPERIMENTAL PROGRAM

Nine trial mixes were prepared by varying the silica fume content and water to powder ratio. Three levels of the silica fume: 3, 6, 9% by mass of powder, three levels of water to powder ratio: 0.3, 0.34, 0.37, and super plasticizer (1.15% by mass of powder) were used for preparing and testing nine trial mixes. For each trial mix, a constant Powder Content: 550 ($kg/m^3$). Lime stone 40% by mass of powder and a constant fine to total aggregate ratio: 0.525 (by mass) of concrete were taken. Proportions of the trial mixes, determined using the ACI method, are presented in Table VI.

## VI. RESULTS AND DISCUSSION

Mixes were prepared and test performed according to procedures described earlier. Table VII provides the details of the rheological properties observed for concrete mixes with silica fumes, Fig. 1 to Fig. 4 below show the effect of silica fume on various rheological and harden concrete properties. From the rheological point of view, a silica fume content of 6% should be recommended. The 28-day strength chart is very intriguing. The compressive strength of SCC mix prepared showed a distinct U-shape curve with respect to w/p ratio. This could be perhaps explained by the fact that at higher w/p ratio, the concrete is more workable and assumes a denser configuration. This phenomenon needs to be further studied.

## VII. CONCLUSIONS

1. Silica fume is a viable secondary mineral material. It leads to higher than usual modulus value and from the mixes studied, it is suggested that no more than 6% silica be replaced by mass.
2. Rheological tests chosen and performed were sufficient to ascertain whether the mix will have all the attributes of SCC or not, i.e., the fresh concrete test used were sufficient to measure the filling ability and passing ability.
3. It is recommended that, at the minimum, Slump test, U-Box and L-box should be performed for the laboratory verification tests.

TABLE V
VISUAL STABILITY INDEX (VSI) RATING CRITERIA

| VSI | Criteria |
|---|---|
| 0 | No evidence of segregation in slump flow patty, mixer drum or wheelbarrow |
| 1 | No mortar halo in slump flow patty, but some bleeding on the surface of concrete mix drum or wheel barrow |
| 2 | A slight mortar halo (<3/8in (10mm)) in slump patty and noticeable layer of mortar on the surface of resting concrete in mixer |
| 3 | Clearly segregating by evidence of large mortar halo(>3/8in (10mm)) and a thick layer of mortar and bleed water in the surface of resting concrete |

TABLE VI
AFFECT OF SILICA FUME

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| sand to total aggregate ratio | 0.525 | | | | | | | | |
| Powder content | 550 kg/m$^3$ | | | | | | | | |
| Lime stone | 40 % | | | | | | | | |
| W/P | 0.3 | | | 0.34 | | | 0.37 | | |
| Silica fume | 3% | 6% | 9% | 3% | 6% | 9% | 3% | 6% | 9% |

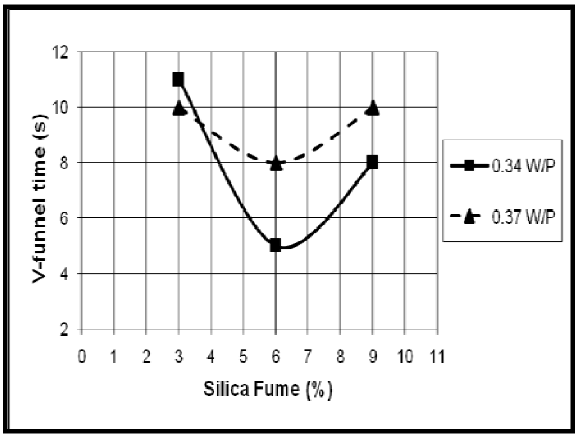


Fig. 1 Silica fume vs. V-funnel

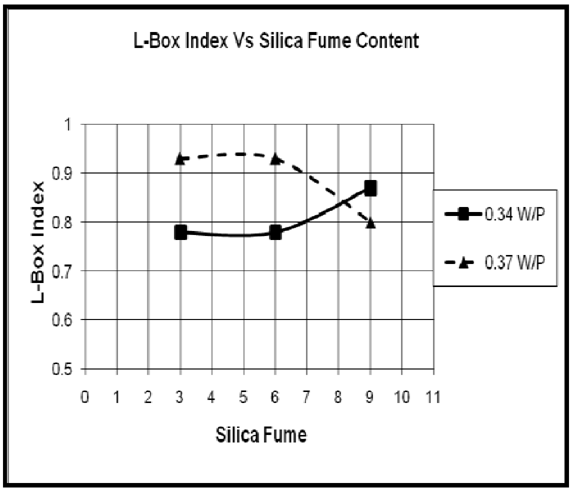


Fig. 2 Silica fume vs. inverted slump

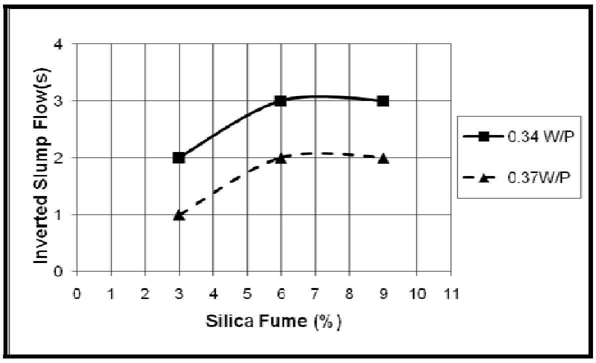


Fig. 3 Silica fume vs. L-box

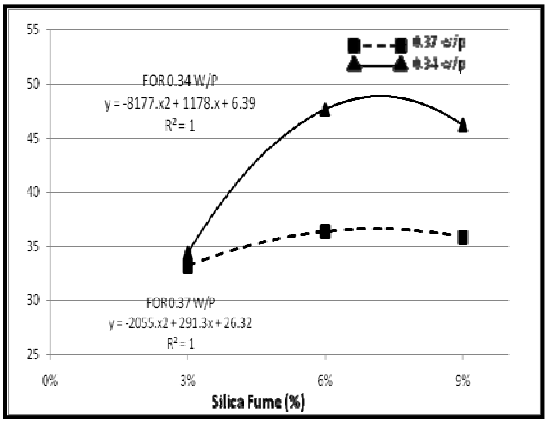


Fig. 4 Compressive strength and silica fume

TABLE VII
WORKABILITY AND COMPRESSIVE STRENGTH RESULTS

| Mix ID w/p | Mix ID SF | Air % | Unit Weight kg/m³ | Slump flow(mm) | T50cm[a] (Sec) | U-Box | L-Box | V-Funnel (Sec) | Slump Flow with J-Ring (mm) | VSI[e] | 28 day's (MPa) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.34 | %3 | 4 | 2298 | 530 | 2 | 0.76 | 0.78 | 11 | 510 | 1 | 36.84 |
| | %6 | 2 | 2285 | 660 | 3 | 0.9 | 0.87 | 5 | 510 | 1 | 47.63 |
| | 9% | 4.5 | 2315 | 550 | 3 | 0.95 | 0.87 | 8 | 520 | 2 | 46.18 |
| 0.37 | %3 | 4 | 2303 | 500 | 2 | 1 | 0.93 | 10 | 530 | 1 | 33.21 |
| | %6 | 6 | 2303 | 600 | 1 | 1 | 0.83 | 8 | 530 | 1 | 36.4 |
| | 9% | 5 | 2347 | 870 | 3 | 1 | 0.68 | 10 | 532 | 2 | 35.89 |

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