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# Properties of Self-Compacting Concrete Containing Mineral Admixtures

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***Abstract:*** *Self-Compacting Concrete is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. This paper presents an experimental investigation on strength aspects like compressive, flexural and split tensile strength of self compacting concrete containing different mineral admixtures and workability tests for different mineral admixtures (slump, L-box, U-box and T50) are carried out. The methodology adopted is that mineral admixtures are replaced by 30%, 40% and 50% for Portland cement and performance is measured and compared. The influence of mineral admixtures on the workability, compressive strength, splitting tensile strength and flexural strength of self-compacting concrete was investigated. The mix proportion is obtained as per the guidelines given by European Federation of producers and contractors of special products for structure. The following inferences were made; optimum dosage of super plasticizer enhanced the flow property of the concrete. As a result, overall improvements in the flow and filling ability of the self-compacting concrete were observed. It is observed that when mineral admixtures used in self-compacting concrete, can reduce the amount of super- plasticizer necessary to achieve a given fluidity. It should be noted that the effect of mineral admixtures on admixture requirements is significantly dependent on their particle size distribution as well as particle shape and surface characteristics. From this view point, a cost effective self-compacting concrete design can be obtained by incorporating reasonable amounts of silica fume, fly ash, and ground granulated blast furnace slag.*
***Keywords:*** *Fly ash, Ground granulated blast furnace slag, self-compacting concrete, silica fume.*

## I. Introduction

Concrete is a widely used construction material around the world, and its properties have been undergoing changes through technological advancement. Numerous types of concrete have been developed to enhance the different properties of concrete. In recent years, the usage of self-compacting concrete in ready mix concrete plants have tremendously increased due to its advantages in consolidation, uniformity and reliability. Self-compacting Concrete is an innovative concrete that does not require any vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. Self-Compacting Concrete is a complex system that is usually proportioned with one or more additions and one or more chemical admixtures. A key factor for a successful formulation is a clear understanding of the role of the various constituents in the mix and their effects on the fresh and hardened properties (Bonen and Shah, 2005). Successful self-compacting concrete must have high fluidity (for flow under self-weight), high segregation resistance (to maintain uniformity during flow) and sufficient passing ability so that it can flow through and around reinforcement without blocking or segregating (Khayat et al. 2002). Super plasticizers added to concrete provide a better workability. One of the disadvantages of self compacting concrete is its cost, associated with the use of chemical admixtures and use of high volumes of Portland cement. The water demand and workability are controlled by particle shape, particle size distribution, particle packing effects and the smoothness of the surface texture (Noor and Umoto, 1999). One alternative to reduce the cost of self-compacting concrete is the use of additions. Due to the better engineering and performance properties, additions such as silica fume, fly Ash, and ground granulated blast-furnace slag are normally included in the production of high-strength and high-performance concrete (Gesoglu et al. 2009). The most often used fillers increasing viscosity of self-compacting concrete mixtures are fly ash, glass filler, limestone powder, silica fume and quartzite filler. More recently, environmental arguments began to prevail, in particular the need to decrease the overall CO2 production related to the use of cement in concrete (Bilodeau and Malhotra, 2000). Fly ash (Sonebi, 2004), ground granulated blast furnace slag and silica fume (Gesoglu et al., 2009) were the most frequently applied in self compacting concrete.

## II. Experimental Investigation

### 2.1 Materials

Ordinary Portland cement of grade 43 conforming to IS: 12269-1987 was used. Locally available river sand conforming to grading zone II of IS: 383-1970 was used and crushed stones of nominal size 12.5mm conforming to IS 383-1970 was used. The specific gravity of coarse aggregate was 2.77. The maximum size of the coarse aggregate was restricted to avoid the blocking effect in self-compacting concrete. The amount of coarse aggregates in self-compacting concrete mixtures is much lower than in traditional vibrated concrete. On the other hand, they contain a high amount of fine fillers and/or additives to increase the viscosity. In this way, the stability of the mix is maintained, bleeding is reduced, and separation of coarser aggregates is avoided (Boukendakdji et al., 2009). The specific gravity of cement and sand was 3.15 and 2.65 respectively. The mineral admixtures like fly ash, GGBS and Silica fume are used. A new generation based polycarboxylic ether was used. In terms of effectiveness polycarboxylic ether is higher compared to other bases and it also works at low dosages than other types of superplasticizers. The pH of super plasticizer was greater than 6.

### 2.2 Mix Proportions

One control and nine mixes with different replacements of mineral admixtures were prepared and examined to quantify the properties of self-compacting concrete. Table 1 presents the composition of self-compacting concrete mixtures. The replacement was done at levels of 30%, 40% and 50% by mass. After iterative trial mixes the water/powder mass ratio (w/p) was selected as 0.35. The total powder content was varied as 400 kg/m$^3$, 450 kg/m3, 500 kg/m$^3$ as iterative values and finally is fixed as 500 kg/m$^3$. A polycarboxylate based high range water reducing admixture was used along with these mixes, apart from the control mix. Some design guidelines have been prepared from the acceptable test methods (Habert, 2009). Many different test methods have been developed in attempts to characterize the properties of selfcompacting concrete. So far no single method or combination of methods has achieved universal approval and most of them have their adherents. Similarly no single method has been found which characterizes all the relevant workability aspects so each mix design should be tested by more than one test method in order to obtain different workability parameters (Bonen et al.,2005).

**Table 1.** Mixture Proportions for Fly Ash Self-Compacting Concrete (Kg/m$^3$)

| Materials | Control | Fly Ash 30% | Fly Ash 40% | Fly Ash 50% |
|---|---|---|---|---|
| Cement | 500 | 350 | 300 | 250 |
| Fly Ash | - | 150 | 200 | 250 |
| Silica Fume | - | - | - | - |
| Blast furnace slag | - | - | - | - |
| Water/Powder | 0.35 | 0.35 | 0.35 | 0.35 |
| Sand | 900 | 900 | 900 | 900 |
| Coarse aggregate | 600 | 600 | 600 | 600 |
| Super plasticizer | 3.5% | 2.2% | 2.15% | 2.1% |

**Table 2.** Mixture Proportions for Silica Fume Self-Compacting Concrete (Kg/m$^3$)

| Materials | Control | Silica Fume 30% | Silica Fume 40% | Silica Fume 50% |
|---|---|---|---|---|
| Cement | 500 | 350 | 300 | 250 |
| Fly Ash | - | - | - | - |
| Silica Fume | - | 150 | 200 | 250 |
| Blast furnace slag | - | - | - | - |
| Water/Powder | 0.35 | 0.35 | 0.35 | 0.35 |

| | | | | |
|---|---|---|---|---|
| Sand | 900 | 900 | 900 | 900 |
| Coarse aggregate | 600 | 600 | 600 | 600 |
| Super plasticizer | 3.5% | 2.1% | 2.07% | 2.0% |

**Table 3.** Mixture Proportions for Blast furnace slag Self-Compacting Concrete (Kg/m$^3$)

| Materials | Control | Silica Fume 30% | Silica Fume 40% | Silica Fume 50% |
|---|---|---|---|---|
| Cement | 500 | 350 | 300 | 250 |
| Fly Ash | - | - | - | - |
| Silica Fume | - | - | -- | - |
| Blast furnace slag | - | 150 | 200 | 250 |
| Water/Powder | 0.35 | 0.35 | 0.35 | 0.35 |
| Sand | 900 | 900 | 900 | 900 |
| Coarse aggregate | 600 | 600 | 600 | 600 |
| Super plasticizer | 3.5% | 2.2% | 2.17% | 2.0% |

### 2.3 Casting, Curing and Testing

Compressive strength studies were studied on cube moulds of 150 mm × 150 mm × 150 mm, while cylindrical moulds of size 150 mm × 300 mm were used for the determination of split tensile strength. The flexural strength studies were carried out in prisms of size 100 mm × 100 mm × 500 mm. For each mixture of fly ash, silica fume, ground granulated blast furnace slag 36 no of specimens were casted and tested for compressive, split and flexure. Before these strength studies the slump flow, L-box, U-box, V-funnel, T50 were done to study the workability properties of self-compacting concrete to access the filling ability and passing ability. The slump flow test was used to evaluate the flow ability of self-compacting concrete in terms of mean spread diameter. The minimum value of self-compacting concrete to be 650 mm and a maximum of 800 mm for a fresh self-compacting concrete. During the slump flow test, the time required to reach 50 cm diameter of slump flow is measured (T50). The V-funnel test is used to determine the filling ability of the concrete. The time taken for the concrete to flow down is noted in seconds. The slump-flow test judges the capability of concrete to deform under its own weight against the friction of the surface with no external restraint present. Because of the viscous nature of some self-compacting concrete mixtures, the slump-flow measurements were carried out. At the same time, the slump-flow time (T50) was measured when the concrete was slumping until it reached 50 cm of flow. The V-funnel and L-box tests were performed according to the procedure given by European federation Committee. The freely as water, at rest it will be horizontal. The acceptable value of filling height is 30 mm maximum as suggested by European standards. The strength studies were carried out at both 7 and 28th day for these mix proportions. Table 4 shows the values of fresh properties of different mixtures used. Tables 5, 6, and 7 shows the mechanical strength obtained for different mixes.

**Table 4.** Fresh Properties of Self Compacting Mixes

| Mixture no | Water/powder | Slump (mm) | V-funnel (sec) | U-Box ($h_2$-$h_1$) mm | L-Box ($h_2$/$h_1$) | $T_{50}$ (sec) |
|---|---|---|---|---|---|---|
| Fly ash-30% | 0.35 | 660 | 10 | 26.5 | 0.9 | 6.1 |
| Fly ash-40% | 0.35 | 675 | 9 | 26 | 0.93 | 6.6 |
| Fly ash-50% | 0.35 | 680 | 9.15 | 25.5 | 0.95 | 7 |
| Silica fume-30% | 0.35 | 650 | 8 | 27 | 0.83 | 5 |
| Silica fume-40% | 0.35 | 660 | 7 | 26 | 0.9 | 5.5 |
| Silica fume-50% | 0.35 | 675 | 6 | 25 | 0.94 | 6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Blast furnace slag-30% | 0.35 | 680 | 10 | 26 | 0.9 | 5 |
| Blast furnace slag-40% | 0.35 | 685 | 8 | 25 | 0.95 | 5.5 |
| Blast furnace slag-50% | 0.35 | 690 | 7 | 24 | 1 | 6 |

**Table 5.** Compressive Strength of Fly Ash, Silica fume, Blast Furnace Slag Mixes

| Water/ powder | Compressive Strength (MPa) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Fly Ash | | | Silica Fume | | | Blast Furnace Slag | | |
| | Mixture no | 7 days | 28 days | Mixture No | 7 days | 28 days | Mixture no | 7 days | 28 days |
| 0.35 | Control | 20 | 30 | Control | 20 | 30 | Control | 20 | 30 |
| 0.35 | Fly ash-30% | 29.16 | 37.18 | Silica fume-30% | 34 | 48.88 | Blast furnace slag-30% | 24.1 | 32.44 |
| 0.35 | Fly ash-40% | 28.6 | 39.13 | Silica fume-40% | 32 | 42.23 | Blast furnace slag-40% | 21.4 | 31.8 |
| 0.35 | Fly ash-50% | 28.73 | 41.42 | Silica fume-50% | 30.15 | 35.14 | Blast furnace slag -50% | 18.2 | 31.55 |

**Table 6**. Split Tensile Strength of Fly Ash, Silica Fume, Blast Furnace Slag Concrete Mixes

| Water/ Powder | Split Tensile Strength (MPa) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Fly Ash | | | Silica Fume | | | Blast Furnace Slag | | |
| | Mixture no | 7 days | 28 days | Mixture no | 7 days | 28 days | Mixture no | 7 days | 28 days |
| 0.35 | Control | 1.08 | 1.74 | Control | 1.08 | 1.74 | Control | 1.08 | 1.74 |
| 0.35 | Fly ash-30% | 1.47 | 2.06 | Silica fume-30% | 1.84 | 2.14 | Blast furnace slag-30% | 1.14 | 1.89 |
| 0.35 | Fly ash-40% | 1.36 | 2.2 | Silica fume-40% | 1.61 | 1.9 | Blast furnace slag-40% | 1.15 | 2.01 |
| 0.35 | Fly ash-50% | 1.28 | 2.36 | Silica fume-50% | 1.49 | 1.51 | Blast furnace slag-50% | 1.16 | 2.09 |

**Table 7.** Flexural Strength of Fly Ash, Silica Fume, Blast Furnace Slag Concrete Mixes

| Water/ powder | Flexural Strength (MPa) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Fly Ash | | | Silica Fume | | | Blast Furnace Slag | | |
| | Mixture no | 7 days | 28 days | Mixture No | 7 days | 28 days | Mixture no | 7 days | 28 days |
| 0.35 | Control | 2.14 | 3 | Control | 2.14 | 3 | Control | 2.14 | 3 |
| 0.35 | Fly ash-30% | 4.58 | 5.8 | Silica fume-30% | 3.69 | 3.1 | Blast furnace slag-30% | 2.24 | 3.2 |
| 0.35 | Fly ash-40% | 4.2 | 5.2 | Silica fume-40% | 4.3 | 3.5 | Blast furnace slag-40% | 2.8 | 3.3 |
| 0.35 | Fly ash-50% | 3.2 | 4.7 | Silica fume-50% | 4.96 | 3.87 | Blast furnace slag-50% | 3.12 | 3.44 |

## III. Results and Discussion

In this study, fresh and hardened properties of self-compacting concrete were investigated by using waste materials (fly ash, silica fume, and blast furnace slag) at three replacement rates for cement. The ability of such studies is done according to appropriate criteria given by European standards. In the present study, such properties of self-compacting concrete produced with fly ash, silica fume and blast furnace slag were investigated based on fresh concrete tests, specifically workability tests, and strength studies.

**3.1 Fresh Properties**

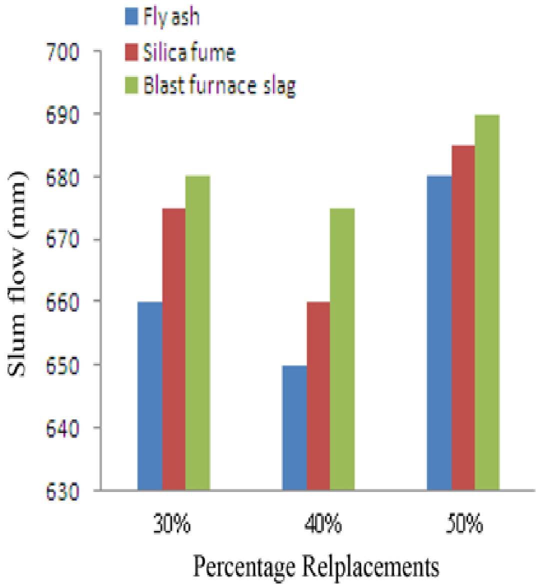
The slump flow values for self-compacting concrete with fly ash, silica fume and blast furnace slag immediately after the mixing process are presented in Table 6. In terms of slump flow, all self-compacting concrete mixtures exhibited satisfactory slump flows in the range of 660-690 mm, which is an indication of a good deformability. Higher replacement levels have shown better slump values which can be inferred from Fig. 2. Also it can be seen that Blast furnace slag series have shown better slump. When cement is replaced by mineral admixtures, a lower dosage of super plasticizer is required to maintain the flow. Fly ash series had more super plasticizer dosage to provide same slump flow than other mixtures and have shown good slump-flow values (Khatib, 2008). Moreover, comparing to the other mineral admixtures, the fly ash particles had a spherical geometry and a coarse particle size, causing a reduction in the surface area. In addition, a partial replacement of cement by fly ash results in higher volume of paste due to its lower density and this increase in the paste volume reduces the friction at the fine aggregate paste interface and improves the cohesiveness and plasticity, and thus leads to increased workability (Sonebi, 2004). A value of at least 650 mm is required for self-compacting concrete. In case of severe segregation, most coarse aggregate will remain in the centre of the pool of concrete and mortar and paste at the periphery of concrete. Hence the value obtained from the experimental investigation is within the limit of European Standards. Water/powder ratio is usually accepted between 0.9 and 1.0 by volume, depending on the properties of the powder (Uysal and Sumer, 2011). For all the mixtures, at constant water/powder ratio and varying percentage of super plasticizer content, an increase in slump flow was observed up to 50% of slag content with an optimum at 30%, and with super plasticizer dosage at 2.2%. T50 times as indicators of viscosity of highly flowable concrete mixes. Lower time indicates greater flowability. The T50 was influenced by the dosage of water and super plasticizer. The volume of coarse aggregate, a good flow ability with increasing fly ash, silica fume and blast furnace slag content till 30% is observed, afterward flow time increases but with some bleeding and segregation.

**Table 8.** Fresh Properties of Self Compacting Mixes

| Mixture no | Water/powder | Slump (mm) | V-funnel (sec) | U-Box ($h_2$-$h_1$) mm | L-Box ($h_2$/$h_1$) | $T_{50}$ (sec) |
|---|---|---|---|---|---|---|
| Fly ash-30% | 0.35 | 660 | 10 | 26.5 | 0.9 | 6.1 |
| Fly ash-40% | 0.35 | 675 | 9 | 26 | 0.93 | 6.6 |
| Fly ash-50% | 0.35 | 680 | 9.15 | 25.5 | 0.95 | 7 |
| Silica fume-30% | 0.35 | 650 | 8 | 27 | 0.83 | 5 |
| Silica fume-40% | 0.35 | 660 | 7 | 26 | 0.9 | 5.5 |
| Silica fume-50% | 0.35 | 675 | 6 | 25 | 0.94 | 6 |
| Blast furnace slag-30% | 0.35 | 680 | 10 | 26 | 0.9 | 5 |
| Blast furnace slag-40% | 0.35 | 685 | 8 | 25 | 0.95 | 5.5 |
| Blast furnace slag-50% | 0.35 | 690 | 7 | 24 | 1 | 6 |

**3.2 Mechanical Properties**

The compressive, split and flexure studies at different ages are shown in the Figs. 2, 3, and 4. When compared to that of the control mixture increasing amounts of mineral admixtures generally decrease the strength. Thus it is clear that the roles of Fly ash and Blast furnace slag act as mineral admixtures reducing the compressive strength of Fly ash and Blast furnace slag series. But, the Silica fume series has shown the best performance both at 7 days and 28 days at 30% replacements. This is due to the physical nature of better packing and fineness of it (Sahmaran et al.,2009). Higher replacements of silica fume also have resulted in decrease in strength. At the early stage, pozzolanic reactions of fly ash and blast furnace slag were not sufficient to increase compressive strength. But at 28 days the slower pozzolanic reactions played a part in the Blast furnace slag mix. In the case of fly ash and blast furnace slag, filling of the voids between the larger cement particles, and increasing production of secondary hydrates by pozzolanic reactions with the lime resulting from the primary hydration enhances compressive strength (Yahia et al., 2005). Furthermore, it chemically reacts with the calcium hydroxide produced by the hydration of the Portland cement to form calcium silicate hydrates (C-S-H) which binds the concrete together.



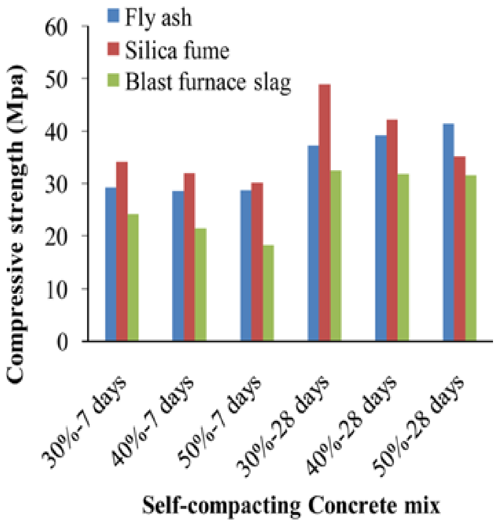




**Fig. 1.** Slump Flow of SCC with Fly Ash, Silica Fume and Blast Furnace Slag Fig. 2. SCC Mix vs Compressive Strength

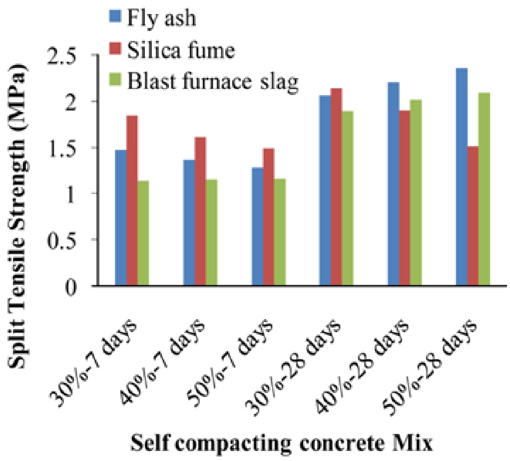



**Fig. 3.** SCC Mix vs Split Tensile Strength

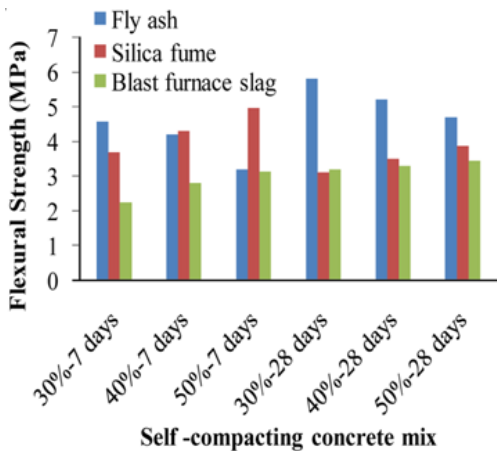



**Fig. 4.** SCC Mix vs Flexural Strength

## IV. Conclusions

The tests were performed to determine the fresh and mechanical properties of Self-Compacting Concrete mixtures and the results of the tests are as follows.

1. All the self-compacting concrete mixes had a satisfactory performance in the fresh state. Among the mineral admixtures considered, the Blast furnace slag series had a good workability properties compared to Fly ash and Silica fume series.
2. In general the use of mineral admixtures improved the performance of self-compacting concrete in fresh state and also avoided the use of viscosity modifying admixtures.
3. The results of the mechanical properties (compressive, split and flexure) had shown significant performance differences and the higher compressive strength has been obtained for Silica fume series. Also the increase in replacement levels has resulted in decrease in strength in silica fume series. So 30% replacement levels could be of optimum consideration for both flowability as well mechanical properties.
4. The evaluation of the mixes indicates the more critical changes in self-compacting concrete occur when there is excess cement, mineral admixtures, less cement, excess superplasticizer, and excess sand, excess coarse aggregate.

5. The most critical test for evaluating the self-compacting concrete loss seems to be slump flow; (i.e) robustness is assured if the parameters of these tests are satisfied.
6. Optimum water/powder ratio was chosen as 0.35 by weight, the ratio greatly beyond or less than this may cause segregation and blocking tendency in self-compacting concrete mixtures.

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