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Influence of fly ash and silica fumes on rheology and mechanical properties of Self Compacting Concrete

J.M. Srishaila[1], K.N. Alok[2], Dr.P.PRAKASH[3], Dr.Veena Jawali[4]

[1](Assistant Professor, Department of Civil Engineering, Dayanand Sagar College of Engineering, Bangalore, India)
[2](Post Graduate Student, Structural engineering, Dayanand Sagar College of Engineering, Bangalore, India)
[3](Professor and HOD, Department of CTM, Dayanand Sagar College of Engineering, Bangalore, India)
[4](Professor, Department of Mathematics, BMS College of Engineering, Bangalore, India)

Abstract: In the present experimental investigation an attempt is made to study the rheological, mechanical properties and relationship between compressive strength, Split tensile Strength, Flexural Strength and modulus of elasticity of Self Compacting Concrete made with replacement of cement by fly ash and silica fumes. Using Fly ash by 15%, 20% and 25% in combination with Silica fumes by 6%, 9% and 12% as partial replacement of cement and keeping water powder ratio 0.36 and superplasticizer 0.6% by weight of cement for all the mixes.

Keywords: *Self Compacting Concrete, Fly Ash, Silica Fume, Workability, compressive strength, split tensile strength, Modulus of elasticity* .

I. INTRODUCTION

The modern concrete consists of various filler materials such as fly ash, micro silica, GGBS etc. The development of Self-Consolidating Concrete (SCC) has recently been one of the most important developments in the building industry. The purpose of this concrete concept is to decrease the risk due to the human factor, to enable the economic efficiency, more freedom to designers and constructors and more human work. There is no standard method for SCC mix design and many academic institutions, ready-mixed, precast and contracting companies have developed their own mix proportioning methods. Mix designs often use volume as a key parameter because of the importance of the need to over fill the voids between the aggregate particles [1].

Self-compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self weight with little or no vibration effort, and which is at the same time cohesive enough to be handled without segregation or bleeding of fresh concrete. SCC mixes usually contain superplasticizer, high content of fines and or viscosity modifying additive (VMA). Whilst the use of superplasticizer maintains the fluidity, the fine content provides stability of the mix resulting in resistance against bleeding and segregation. The use of fly ash and blast furnace slag in SCC reduces the dosage of superplasticizer needed to obtain similar slump flow compared to concrete mixes made with only Portland cement [2].

To achieve satisfactory combinations of high fluidity and stability, SCC requires high powder
volumes at relatively low water/powder ratios with significant quantities of superplasticizers. The powder generally consists of a combination of Portland cement with one or more additions such as fly ash, silica fumes, GGBS or metakaolin can be used . In the present investigation we have used fly ash and silica fumes as additives [3].

II. RESEARCH SIGNIFICANCE

For a newly developed material like Self Compacting Concrete studies on workability and mechanical properties such as Compressive, Split Tensile and Flexural strength are of paramount important for instilling confidence amongst the engineers and builders. The literature indicates that while some studies are available on the Compressive Strength, Split Tensile Strength and Flexural Strength of Self Compacting Concrete. Comprehension studies which involve relationship between the parameters Compressive Strength, Split Tensile Strength, Flexural Strength are not available Self Compacting Concrete Mixes. Hence, considering the gap in the existing literature, an attempt has been made to obtain a relationship between the splitting tensile strength, Flexural Strength , Compressive strength and Young's modulus of concrete .

III. MATERIALS AND METHODOLOGY

Cement: Ordinary Portland cement of 53 grade is used and its physical properties are shown in table 1:

Table 1-Physical properties of Cement

Sl No	Properties		Results	IS:12269-1987
1	Standard Consistency		31%	---
2	Fineness % (retained on 90µ sieve)		3%	≤10%
3	Soundness (By Le Chatelier)		4mm	≤10mm
4	Initial setting time (mm)		48	≥30
5	Final setting time (min)		364	≤600
6	Specific Gravity		3.15	---
7	Compressive Strength (N/mm^2)	28 days	55	≥53

Fine Aggregate (Sand): In this work manufactured sand 4.75 mm down having specific gravity 2.59 and fineness modulus 3.43 confirming zone II as per IS: 383-1997 is used.

Coarse Aggregate (CA): Crushed granite aggregates are used and maximum size of aggregate used is 20mm.Specific gravity is2.70 and moisture content 0.2%.

Chemical Admixture: Chemical admixtures are mainly used to produce high strength mix (> 50Mpa) and to get workable mix at low water cement ratio. $P^H \geq 6$ and chloride content is nil.

Fly Ash (FA): Class F fly ash confirming to IS: 3812 – 1981as replacement of cement. Physical and chemical properties of Fly ash are shown in table 2:

Table 2-Physical and Chemical properties of Fly Ash

Sl No	Parameter	Quantity (% wt)
1	Silicon Dioxide (SiO_2)	62.63
2	Alumina (Al_2O_3)	23.35
3	Iron oxide(Fe_2O_3)	3.93
4	Calcium oxide (CaO)	2.04
5	Magnesium oxide (MgO)	0.46
6	Sulfur tri oxide (SO_3)	1.34
7	Sodium oxide (Na_2O)	0.032
8	Potassium oxide (K_2O)	0.030
9	Loss on ignition % by mass	0.39
10	Bulk density	1.11gm/cc

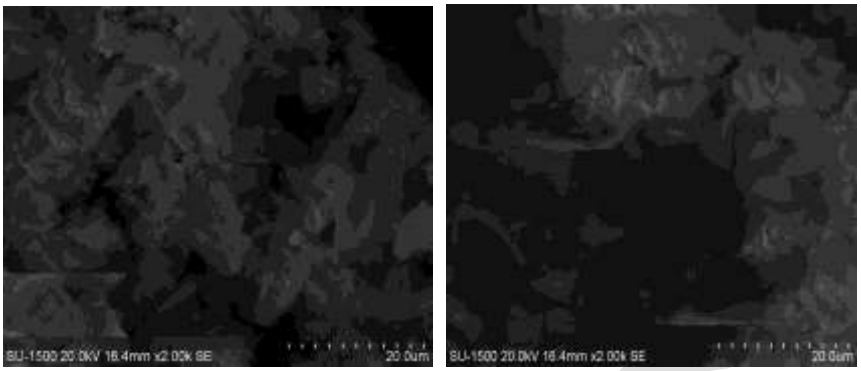


Figure 1: Scanning Electron Microscopic Images (SEM) of Fly Ash

Silica Fumes: It is a very fine and spherical shaped mineral admixture. The physical and chemical properties of silica fumes are shown in table 3:

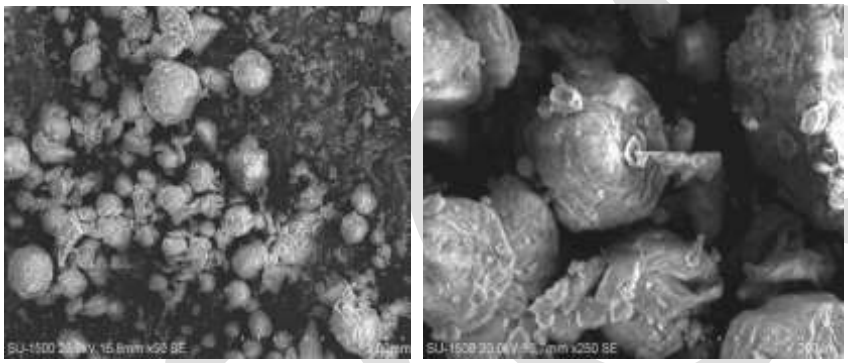


Figure 2: Scanning Electron Microscopic Images (SEM) of Silica fume.

Table 3- Physical and chemical properties of Silica fumes

Sl No	Parameter	Value	ASTM-C-1240
1	SiO2	91.9%	Min 85%
2	Loss On Ignition	2.8%	Max 6%
3	Moisture	0.3 %	Max 3%
4	Pozz. Activity Index	133%	Min 105%
5	Specific Surface Area	22 m^2/gm	Min 15 m^2/gm
6	Bulk Density	601	550-700
7	+ 45 Microns	0.2%	Max 10%

Mix proportion for 1Cum of concrete: Table 4 gives the quantities of materials required for self compacting concrete mix, replacing fly ash 15%, 20% and 25% and silica fumes by 6%, 9% and 12%.

Table 4: Mix proportion of SCC

Mix	OPC Kg/m^3	FA Kg/m^3	SF Kg/m^3	Sand Kg/m^3	CA Kg/m^3	Water Kg/m^3	SP Kg/m^3	W/P Ratio	Density Kg/m^3
Mix 1	441.21	59.07	24.42	879.73	714.42	189.32	3.148	0.36	2380
Mix 2	424.46	59.07	36.63	879.73	714.42	189.32	3.120	0.36	2386

Mix 3	407.70	59.07	48.84	879.73	714.42	189.32	3.093	0.36	2415
Mix 4	413.29	78.76	24.42	879.73	714.42	189.32	3.098	0.36	2434
Mix 5	396.53	78.76	36.63	879.73	714.42	189.32	3.071	0.36	2450
Mix 6	379.78	78.76	48.84	879.73	714.42	189.32	3.044	0.36	2468
Mix7	385.36	98.45	24.42	879.73	714.42	189.32	3.049	0.36	2386
Mix 8	368.61	98.45	36.63	879.73	714.42	189.32	3.022	0.36	2430
Mix 9	351.85	98.45	48.84	879.73	714.42	189.32	2.994	0.36	2435

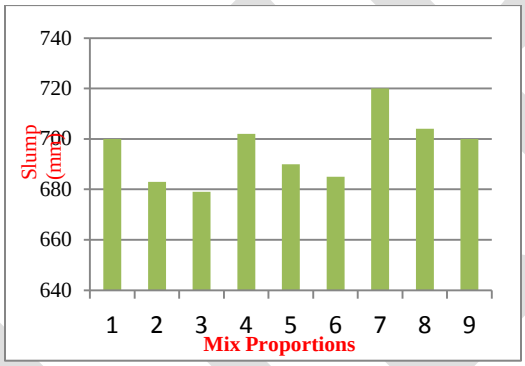
IV. RHEOLOGY AND HARDENED PROPERTIES OF CONCRETE

Tests and results for Fresh Properties of SCC:

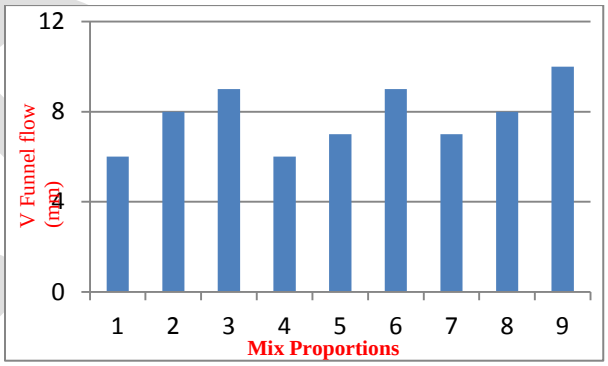
The following are the results obtained for different mix proportions which satisfies the EFNARC guidelines and are shown in Table 5

Table 5- Fresh Properties of SCC

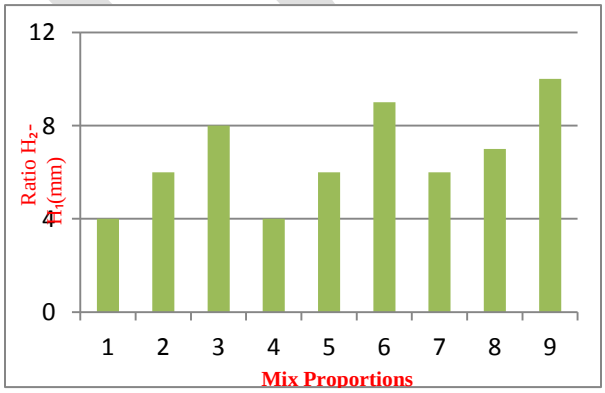
Mix	Slump Flow (mm)	V-Funnel (Sec)	J-Ring (mm)	L-Box H_2/H_1
Mix 1	700	6	4	0.88
Mix 2	683	8	6	0.86
Mix 3	679	9	8	0.85
Mix 4	702	6	4	0.89
Mix 5	690	7	6	0.87
Mix 6	685	9	9	0.84
Mix 7	720	7	6	0.85
Mix 8	704	8	7	0.88
Mix 9	700	10	10	0.89



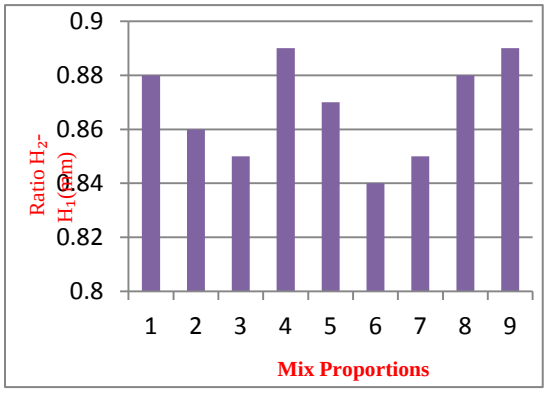
Graph 1: Slump Flow v/s Mix Proportions



Graph 2: V-Funnel Flow Time v/s Mix Proportions



Graph 3: J-Ring Flow v/s Mix Proportions



Graph 4: L-Box Ratio v/s Mix Proportions

Tests and results for mechanical properties of SCC

Concrete specimens are cured for 28 days to determine the hardened properties. Cubes are subjected to strength under compression, cylinders to tensile strength test and beam for flexural test.

Table 6- Test results of Mechanical Properties

Mix	Compressive Strength ($N/mm^{2)}$ 28days	Split Tensile Strength ($N/mm^{2)}$ 28 days	Flexural Strength ($N/mm^{2)}$ 28days	Young's Modulus ($KN/mm^{2)}$ 28days
Mix 1	43.93	4.09	4.95	34.79
Mix 2	45.55	4.16	5.29	35.43
Mix 3	51.63	4.19	5.51	37.72
Mix 4	55.45	4.31	5.71	39.09
Mix 5	57.55	4.51	5.86	39.82
Mix 6	61.32	4.66	6.25	41.11
Mix 7	55.61	4.75	5.85	39.13
Mix 8	53.5	4.65	5.59	38.40
Mix 9	52.12	4.59	5.46	37.90

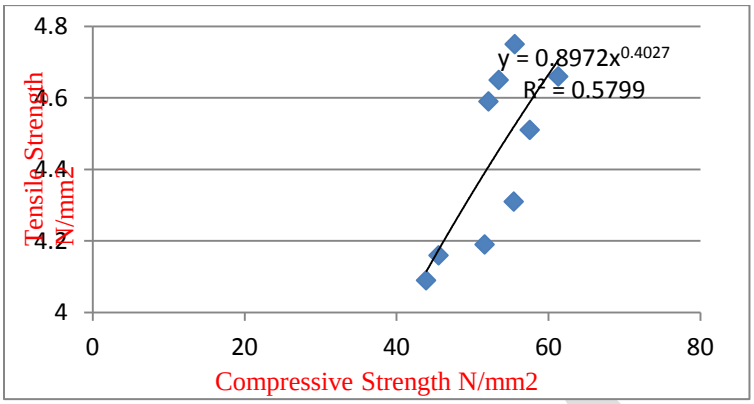
Fig 3: Compression Test

Fig 4: Split Tensile Strength Test

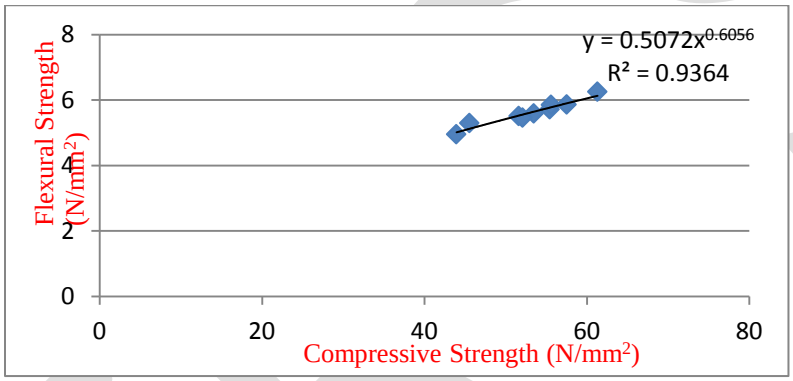
Fig 5: Flexural Strength Test

Fig 6:Modulus of Elasticity (E) Tes

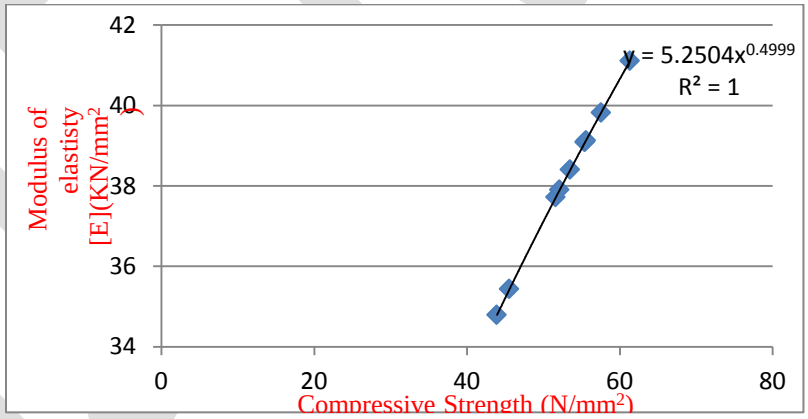
Relationship between Mechanical properties:



Graph 5-Compressive Strength vs Split Tensile Strength



Graph 6-Compressive Strength vs Flexural Strength



Graph 7- Compressive Strength vs Modulus of Elasticity

V. Discussion and Conclusion

The tests were performed to determine the fresh properties and to evaluate the relationship between mechanical properties of Self Compacting Concrete mixtures and the results of the tests are as follows:

- Workability of the mix increases as the percentage of silica fume decreases. The mix with 6% silica fume as replacement of cement gives better workability when compared to mixes with 9% and 12 % silica fume as replacement of cement.
- Scanning Electron Microscope images of mineral admixtures fly ash and silica fumes clearly shows how the shape of particles plays an important role in workability of the mix.
- The Relationship between Compressive, Split Tensile, Flexural Strength and modulus of elasticity of Self Compacting Concrete are in accordance with power's law.
- The Relationship between Compressive Strength – Split Tensile Strength is given by

ft= $0.897fck^{0.402}$ with coefficient of variation $R^2 = 0.579$.

- The Relationship between Compressive Strength –Flexural Strength is given by fcr= $0.507fck^{0.605}$ with coefficient of variation $R^2 = 0.936$.
- The Relationship between Compressive Strength –Modulus of elasticity is given by E= $5.250fck^{0.499}$ with coefficient of variation $R^2 = 1$.

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