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"Experimental Study on Properties of Concrete by Partial Replacement of Cement With Silica Fume"

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Abstract
This study investigates the properties of concrete partially replaced with silica fume (SF). SF is an ultrafine byp roduct of silicon and ferrosilicon industries. Partial replacement of Portland Slag Cement (PSC) with SF was d one at 0%, 4%, 8%, 12%, and 16%. Results show that workability decreases, while compressive, split tensile, an d flexural strengths increase up to 8-12% SF replacement. Economic analysis reveals a decrease in concrete pr oduction cost with increased SF replacement. Optimal replacement ratio is between 8-12%.
Keywords: *Silica Flume, cement, concrete, partial replacement, Experimental study.*

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I. INTRODUCTION

Cementing materials have been crucial in construction since ancient civilizations. The Egyptians used calcined gypsum, while the Greeks and Romans used lime to make mortar or concrete. Silica fume, an ultrafine powder, is a byproduct of silicon and ferrosilicon alloy production. It's used to improve concrete properties, such as compressive strength, bond strength, and abrasion resistance.

Silica fume has been used in concrete for over 25 years, available in slurry or dry forms. It affects the properties of fresh and hardened concrete, increasing water demand and slump loss. Silica-fume concrete has lower creep and drying shrinkage, and higher compressive strength. It also reduces permeability and increases chemical attack resistance.

However, silica-fume concrete requires early-age moist curing to prevent shrinkage and cracking. Accelerated curing can be effective, but may increase moisture loss and reduce ultimate strength. Prolonged curing is recommended for optimum results.

II. LITERATURE REVIEW

2.1 **Alaa M. Rashad et al. (2013)** produced high-volume fly ash (HVFA) concrete by replacing 70% of Portland cement with Class F fly ash. They modified HVFA by replacing 10% and 20% of fly ash with silica fume (SF) and ground granulated blast-furnace slag (GGBS). The results showed that HVFA concrete with SF or SF-GGBS combinations had higher abrasion resistance, while HVFA with GGBS had lower abrasion resistance. Compression and abrasion tests were conducted after curing for 7-180 days.

Vikas Srivastava et al. (2012) investigated the effect of silica fume on concrete's mechanical properties. Silica fume reduced workability, but in some cases, improved it. Compressive strength increased significantly (6-57%) depending on the replacement level. Tensile and flexural strengths were similar to conventional concrete. Silica fume improved bond strength and had a similar modulus of elasticity to conventional concrete. The study highlights the benefits of silica fume in enhancing concrete's mechanical properties, particularly compressive strength.

Tongyan Pan et al. (2012) assessed modified silica fume's (MSF) effectiveness in concrete. Dynamic flexural tests and numerical analyses were conducted. A 3D micromechanical model using discrete element method (DEM) studied stiffness and damping behavior. Results showed 10% MSF significantly enhanced concrete's storage and loss moduli and loss tangent. The DEM model can evaluate and design energy-absorbing concretes for military and civil applications. MSF's addition improved concrete's mechanical properties, making it suitable for specialized applications.

III. EXPERIMENTAL WORK

3.1 Silica fume: Silica fume was obtained from Burdwan, West Bengal. The tests conducted on silica fume for the present thesis are fineness test, bulk density, specific gravity, etc. The chemical composition and physical properties of silica fume are given below in table 3.1 & table 3.2 respectively.

Table 3.1: Chemical composition of silica fume

Constituents	SiO_2	Al_2O_3	SO_3	Fe_2O_3	CaO	K_2O	MgO	Na_2O	LOI
Content (%)	**85.59**	**3.76**	**2.73**	**2.07**	**0.26**	**0.56**	**0.76**	**0.15**	**2.79**

Table 3.2: Physical properties of silica fume

Sl. No.	Parameter	Test results
1.	Specific Gravity	2.20
2.	Bulk Density	0.61 gm/cc
3.	Sieve analysis	2.5 % residue on 90 µ sieve

Table 3.3: Physical and Mechanical Properties of cement

Properties	Results	Standard Limits (IS: 455)
Consistency	32%	_
Soundness	Expansion 3.5 mm	<10mm
Initial setting time (min)	80 minutes	>30 min
Final setting time	275 minutes	<600 min
Specific gravity	3.12	_
Fineness	4.0% Retain on 90 micron sieve	<10mm
Compressive strength 1. 3days 2. 7days 3. 28 days	N/mm^2 24.00 31.00 38.00	N/mm^2 >16 >22 >33

Table 3.4: Sieve Analysis of Fine Aggregate (Weight of sample = 1000gms**)**

IS Sieve (mm)	Wt. Retained(gms)	% Retained	% Cum Wt. (gms)	% Passing	Remarks
4.75 mm	11	1.10	1.10	98.90	Sand Zone II as per IS: 383-1970 CLAUSE 4.3 TABLE 4
2.36 mm	19	1.90	3.00	97.00	
1.18 mm	101	10.10	13.10	86.90	
600 micron	312	31.20	44.30	55.70	
300 micron	394	39.40	83.70	16.30	
150 micron	142	14.20	97.90	2.10	

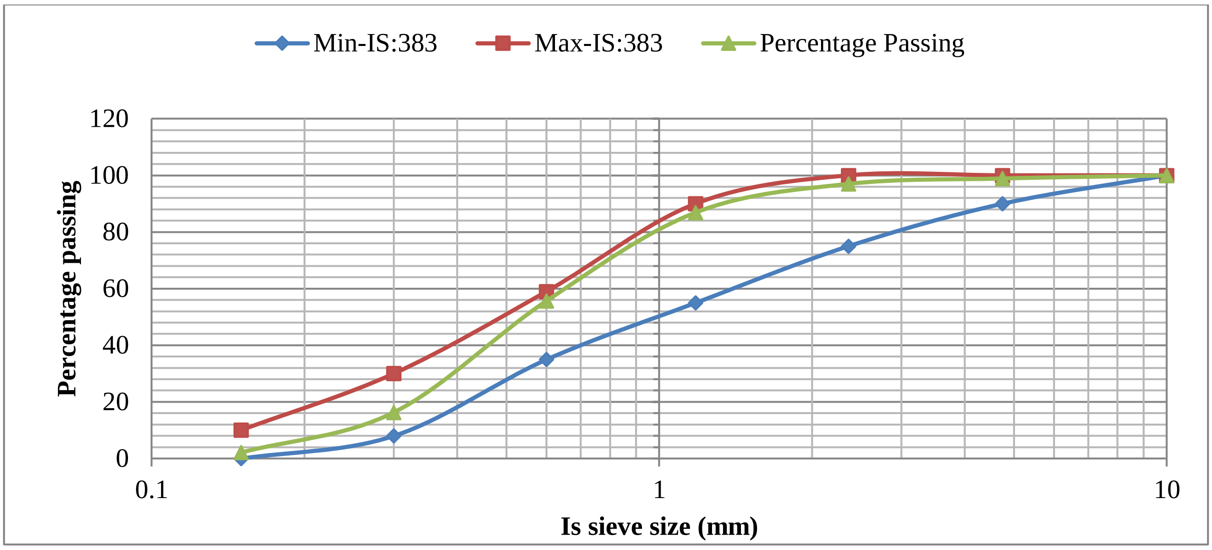

Fig. 3.1: Particle size distribution of fine aggregate

Table 3.5: Sieve Analysis of Coarse Aggregate (Weight of sample = 10000gms)

IS Sieve (mm)	Wt. Retained(gms)	% Retained	% Cum Wt. (gms)	% Passing
40 mm	-	0	0	100
20 mm	560	5.60	5.60	94.40
10 mm	5996	59.96	65.56	34.44
4.75 mm	2529	25.29	90.85	9.15

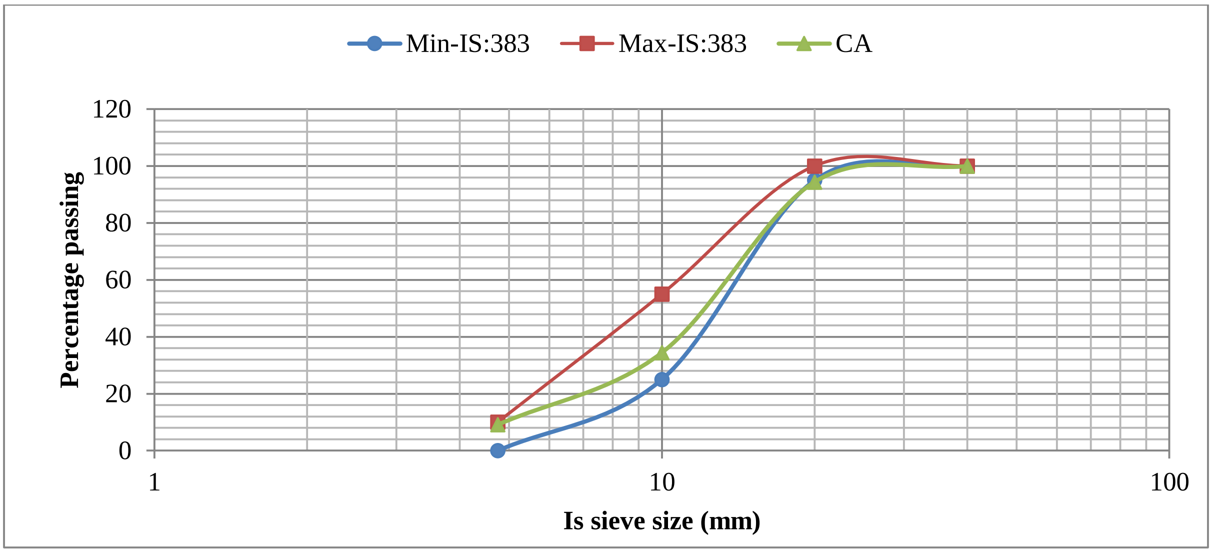

Fig. 3.2 Particle size distribution of coarse aggregate

IV. RESULT AND DISCUSSION

4.1 Composition of (cement + silica fume) concrete

To study the behavior of fresh and hardened concrete by using silica fume as a partial replacement of PSC, a mix design of concrete has being selected. The mix design of concrete used for this thesis is explained in appendix I.

For the investigations conducted in this thesis, 0%, 4%, 8%, 12% and 16% replacement (by weight) of PSC with silica fume is done. In this present study the concrete mixes are represented as M_0, M_4, M_8, M_{12} and M_{16} at partial replacement of PSC cement with silica fume by 0%, 4%, 8%, 12% and 16% respectively.

Table 4.1 Composition of (cement + silica fume) concrete

Mix	Water (kg/m^3)	Silica fume (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
M_0	196.11	0	432.55	649.90	1192.65
M_4	196.11	17.30	415.25	649.90	1192.65
M_8	196.11	34.60	397.95	649.90	1192.65
M_{12}	196.11	51.90	380.65	649.90	1192.65
M_{16}	196.11	69.20	363.35	649.90	1192.65

The table above clearly shows that 0%,4%,8%,12% and 16% PSC is replaced by silica fume only and all the other ingredients of concrete remains same.

4.2 Study of workability of fresh concrete

Each of the concrete mix was tested for its workability. Here slump test and Vee-Bee test has being done to examine the degree of workability.

4.2.1 Slump test

The slump value obtained for M_0, M_4, M_8, M_{12} and M_{16} are given in table 4.2.

Table 4.2 Slump value for different mix

S.No.	Mix	Slump (mm)
1	M_0	46
2	M_4	40
3	M_8	32
4	M_{12}	24
5	M_{16}	15

This slump value is shown below in bar chart

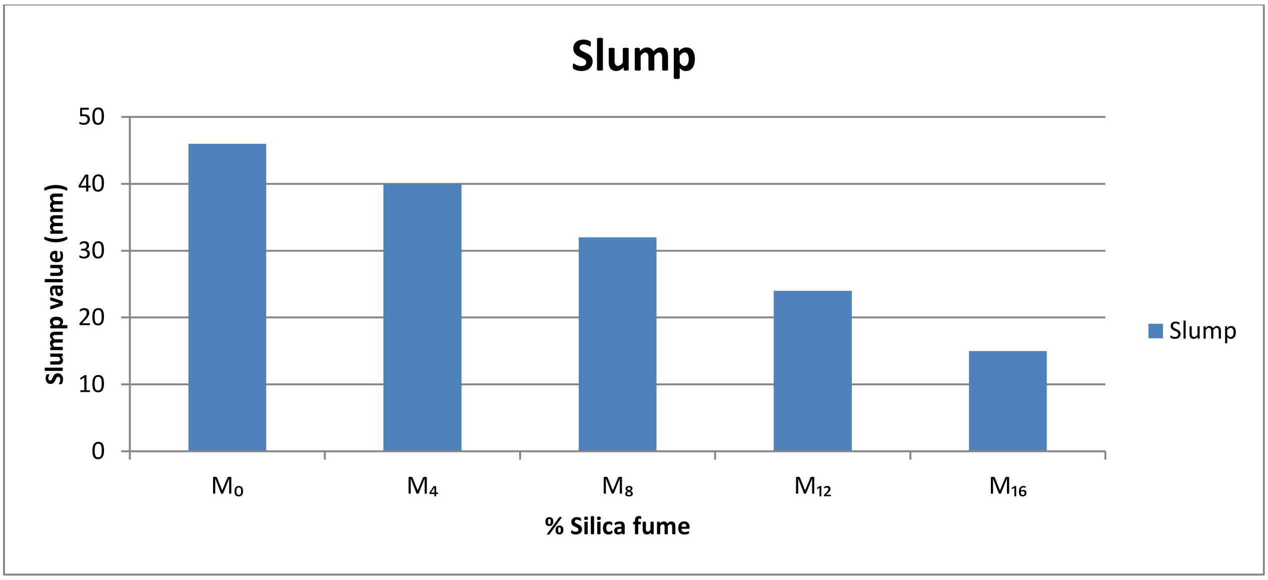

Fig 4.1 Slump value for different mix

4.2.2 Vee-Bee test

The Vee-Bee (time) obtained for M_0, M_4, M_8, M_{12} and M_{16} are given in table 4.3.

Table 4.3 Vee-Bee (time) value for different mix

S.No.	Mix	Vee-Bee (time)
1	M_0	4 sec
2	M_4	5.5 sec
3	M_8	6.5 sec
4	M_{12}	8 sec
5	M_{16}	9 sec

This Vee-Bee (time) is shown below in bar chart

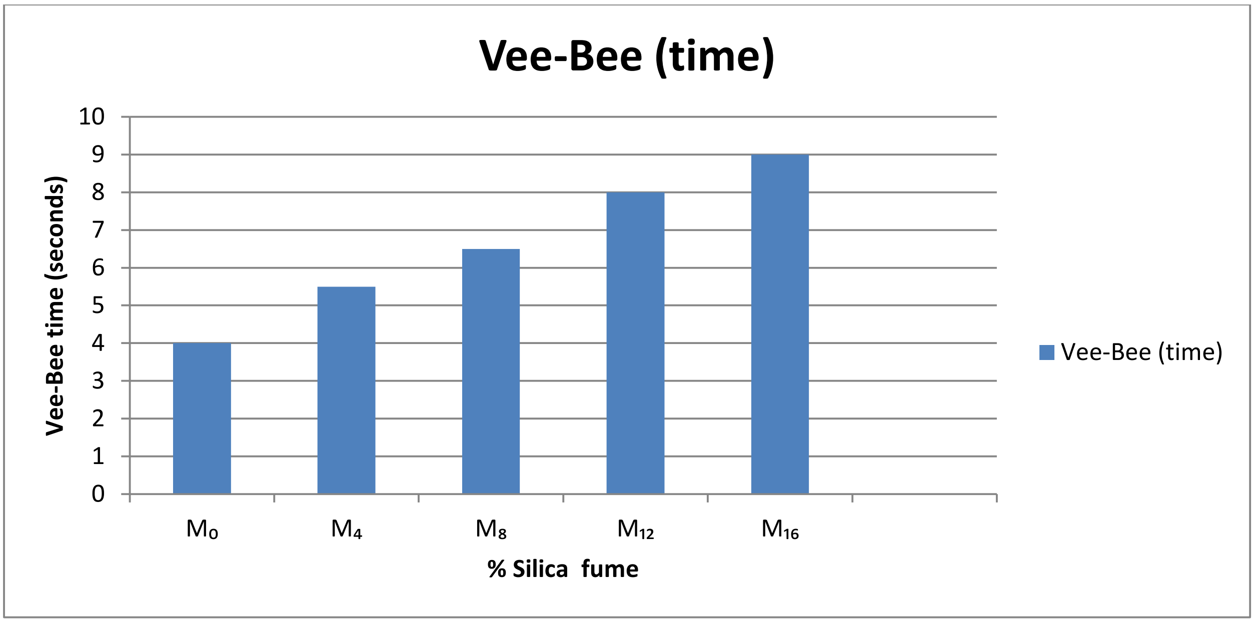

Fig 4.2 Vee-Bee (time) for different mix

Table 4.4 Compressive strength test data after 7 days

Mix	Sample	Cross-sectional area (mm^2)	Failure load (KN)	Compressive strength (N/mm^2)	Avg. compressive strength (N/mm^2)	% variation of compressive strength w.r.to M_0
M_0	1	225 x10^2	670	29.77	29.92	0
	2	225 x10^2	670	29.77		
	3	225 x10^2	680	30.22		
M_4	1	225 x10^2	710	31.55	31.84	+6.41
	2	225 x10^2	710	31.55		
	3	225 x10^2	730	32.44		
M_8	1	225 x10^2	750	33.33	33.92	+13.36
	2	225 x10^2	760	33.77		
	3	225 x10^2	780	34.66		
	1	225 x10^2	700	31.11	31.85	+6.45

M_{12}	2	225 x10^2	720	32.00		
	3	225 x10^2	730	32.44		
	1	225 x10^2	660	29.33		
M_{16}	2	225 x10^2	680	30.22	30.22	+1.00
	3	225 x10^2	700	31.11		

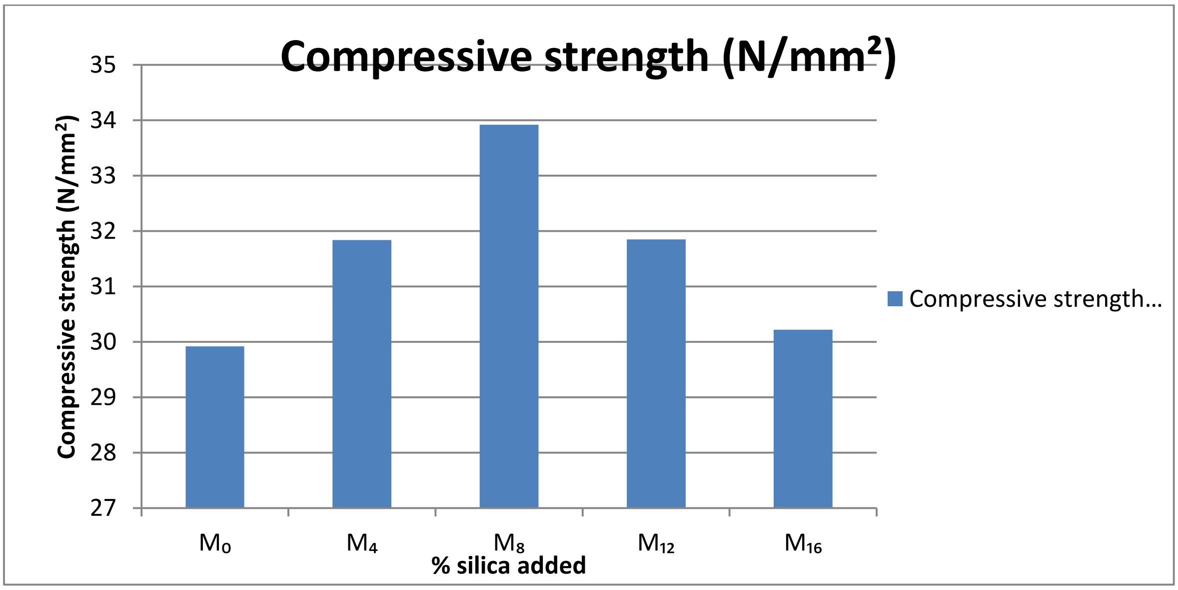

Fig 4.3 Compressive strength test data after 7 days

V. CONCLUSION

Replacing Portland Slag Cement (PSC) with silica fume decreases slump value and workability, but increases compressive, split tensile, and flexural strengths up to 8-12% replacement. Optimum replacement is 8% for compressive and flexural strengths, and 12% for split tensile strength. Total replacement can be up to 16%. Cost analysis shows a 3.21% reduction in concrete cost with 16% cement replacement. The study concludes that 8% PSC replacement with silica fume improves concrete's mechanical properties while reducing cost.

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