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Impact of Silica Fume on Fly Ash Based Concrete Material

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Abstract: Fly ash, being a by-product, discarded and dumped as the power plant waste, is found to be highly toxic with its pozzolanic property. It can be utilised as a construction material to substitute cement. Along with fly ash, additional waste materials such as silica fume and rice husk have diversified applications to enhance the strength of the concrete material. In the present study, concretes are being prepared using variable combinations of fly ash, silica fume and rice husk dust, and their physical and mechanical properties are studied extensively. It is being observed that the addition of silica fume alone in the fly ash could produce concrete blocks with a compressive strength of 35 MPa whereas when silica fume is added along with rice husk powder, the compressive strength could be raised up to 40 MPa. Both types of concrete blocks are subjected to curing period of 14 days to 21 days. The result revealed that block containing silica fume shows corrosion resistance property, whereas blocks containing a combination of rice husk dust and silica fume shows both the property of hydrophobicity as well as corrosion resistivity. The study summarised the fact that by exploring the chemical and mechanical properties of some of the waste material, it is possible to prepare a hydrophobic, corrosion resistance block that could replace the use of cement in the concrete and contribute maximum to get rid of environmental pollutions.

Key words: Silica fume, concrete material, corrosion resistance, hydrophobicity.

Introduction

Silica fume is generated from an electrical furnace during the reduction of quartz to produce high-grade silicon (ACI, 234R-96, 1996). This waste material can be used as an admixture to produce durable concretes with high compressive strength (Antonovich and Goberis, 2003). Many researchers have carried out an extensive study to estimate the strength (Aitcin et al., 1981) developed in silica fume added concretes (ASTM, 2012). Many researchers have studied the impact of silica fume, partially replaced with cement for M 20 grade of concrete (Bayasi and Zhou, 1993). The data revealed that M 20 grade of concrete with water to cement ratio of 2:1 when used could be subjected to replacement of 10% to 20% of silica fume (Kumar et al., 2012) to obtain high strength concretes. The curing period is set to a maximum of up to 28 days, and the result revealed that for 20% replacement of cement (Mittal et al., 2013), the compressive strength could be modified up to 32.29 MPa (Dash et al., 2018). Similarly, researchers did extensive research on the replacement of silica fume with cement in hardened concrete materials (Kadri and Duval, 1998). Concretes of various shapes were being designed (i.e. cylindrical and cubic) with the replacement of 10% cement (IS 456:2000). The data revealed that in comparison to general hardened concrete the silica fume-based concretes showed

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an enhancement of 19.6% to 16.82% for cubic and cylindrical shapes, respectively (Kumar et al., 2013). Scientists have studied the impact of silica fume on M30 grade concrete by replacement of cement with 10% silica fume (Sakr, 2006). When 15 % silica fume is added, there is a drastic decrease in the compressive strength with a variation between 23.98 MPa till 20.22 MPa (Kumar et al., 2014). With a replacement of 10% of cement with silica gel, the compressive strength has enhanced from 16.15% to 29.24%.

Investigations have been carried out to study the impact of silica fume on conventional concrete (Gupta and Gupta, 2012) and could prove that the optimum compressive strength is achieved with 20% cement replacement when the concrete is cured for 28 days (Yogendran et al., 1987).

Keeping in view the above observations, in the present study an attempt has been made to prepare a fly ash-based concrete by substituting cement with silica fume at a variable ratio. The result revealed that fly ash, being a pozzolanic material, has high compressive strength and could be fabricated by using 50% silica fume as a substitute for cement. The compressive strength could be reached up to 42 MPa with an optimum substitution of 48% cement with silica fume and 15% with rice husk powder.

Materials and Method

For the experiment, fly ash has been procured from the NALCO power plant and the composition is mentioned in Table 1.

The silica fume used in the study has the following composition as given in Table 2.

The rice husk powder composition is represented in Table 3.

The mix design for the above three components is represented in Table 4 as below:

With variable composition, five different concrete blocks are prepared and subjected to their physico-chemical-mechanical study.

Experimental Procedure

The experiments were conducted to verify the physical, chemical and mechanical properties of the concrete blocks. The blocks are made up of different shapes i.e. rectangular, square and cylindrical.

Result and Discussion

The concrete blocks made up of various waste materials are subject to the estimate of the following physical properties as given in Table 5. The specific gravity

Table 1: Chemical composition of fly ash

SiO_2	*Al_2O_3*	*Fe_2O_3*	*CaO*	*MgO*	*SO_3*	*K_2O*	*LoI*
59.00	21.00	3.70	6.90	1.40	1.00	0.90	4.62

Table 2: Chemical composition of silica fume

SiO_2	*Al_2O_3*	*Fe_2O_3*	*CaO*	*MgO*	*SO_3*	*LoI*	*K_2O*	*Na_2O*
89	0.47	1.53	0.89	1.6	0.43	4.88	1.11	0.22

Table 3: Chemical composition of rice husk ash powder

SiO_2	*Al_2O_3*	*Fe_2O_3*	*CaO*	*Mg*	*K_2O*	*Na_2O*	*P_2O_5*
93.4	0.05	0.06	0.31	0.35	1.4	0.1	0.8

Table 4: Mix design for concrete blocks

Sl. No.	*Cement kg/m^3*	*Silica fume (kg/m^3)*	*Rice husk ash (kg/m^3)*	*Fine aggregate (kg/m^3)*	*Coarse aggregate (kg/m^3)*	*Water to binder*	*Water (kg/m^3)*	*Admix (kg/m^3)*
Concrete Block - I	500	50	25	1300	435	0.30	180	50
Concrete Block - II	475	75	31.25	1450	585	0.30	240	62.5
Concrete Block - III	450	100	37.50	1600	735	0.30	300	75
Concrete Block - IV	425	125	43.75	1750	885	0.30	360	87.5
Concrete Block - V	400	150	50	1900	1035	0.30	420	100

Table 5: Specific gravity of different concrete blocks

Sl. No.	*Specific Gravity*		
	Square Blocks	*Rectangular Blocks*	*Cylindrical Blocks*
Concrete Block - I	1.96	1.84	1.78
Concrete Block - II	2.38	2.18	1.92
Concrete Block - III	2.73	2.58	2.23
Concrete Block - IV	2.76	2.51	2.27
Concrete Block - V	2.78	2.49	2.28

in terms of structural arrangements is represented in Figure 1.

Specific Gravity

Specific gravity of various concrete blocks are being tested, having variable ratio of composition along with shape and size, The data obtained are incorporated in Table 5.

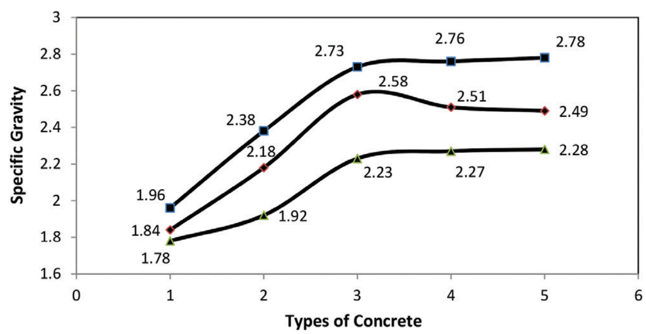

Figure 1: Specific gravity of various concrete blocks depending on shape parameters.

Percentage of Water Absorption

The water absorption parameter is tested for the concrete blocks made up of a combination of rice husk ash, silica fume, fly ash, etc. The data obtained are represented in Table 6. The water absorptivity depends on the porosity and permeability of the concrete. Also, the parameters are partially dependent on (a) concrete mixture proportion, (b) the presence of chemical admixture and supplementary cementitious materials, (c) composition and characteristic of cementitious components and aggregates and (d) the entrained air content. (e) Type and duration of cursing. (f) The degrees of hydration (or) age. (g) Presence of micro cracks. (h) The presence of surface treatments such as sealers or form oil. (i) Placement method including consolidation and finishing.

Water absorption is also strongly affected by the moisture condition of the concrete at the time of testing.

In terms of specific gravity, it has been found that concrete blocks of variable shape and commotion show the difference in specific gravity. In most concrete structures, square-shaped concretes show the highest specific gravity followed by rectangular and cylindrical as well. Second, the observations revealed that out of fire different concrete blocks CB-III made up of the ratio 450:100:375:1600:735:0.30:300:75 of Cement: Silica fume: Rice husk ash: Fine aggregate: Coarse aggregate: Water to binder: Water: admixture, is found to have a consistency and effective specific gravity for further applications. Thus, concrete blocks made with an effective combination could produce a high specific gravity concrete material.

Similarly, in terms of % water absorption, it has been observed that concrete block-III, II and I showed an average water absorption of 5.55% when subjected to curing for a period of 45 days. Interestingly for all other blocks (i.e. I, II, V), there is a gradual rise in water absorption from day one to 45 days. In the case

Table 6: Curing period and water absorptivity of concrete blocks

Days	*1 Day*	*2 Day*	*5 Day*	*10 Days*	*20 Days*	*30 Days*	*45 Days*
Concrete Block - I	0.56	1.11	2.08	3.42	4.15	5.41	5.58
Concrete Block - II	0.72	1.23	2.22	3.61	4.58	5.52	5.60
Concrete Block - III	0.81	1.45	2.5	3.7	4.82	5.64	5.55
Concrete Block - IV	1.18	2.59	3.62	4.68	5.03	5.72	5.70
Concrete Block - V	1.23	2.62	3.74	4.70	5.12	5.78	5.82

of concrete Block III and IV, the maximum absorption is obtained at 30 days when extended to 45 days, there is a gradual decrease in absorption rate. The detail is represented in Figure 2.

Mechanical Property

For the study of mechanical properties, an attempt has been made to estimate the mechanical parameters such as compressive strength, split tensile strength and flexural strength, given in Table 7.

Compressive Strength

Table 7 represents the compressive strength of the concrete blocks made up of silica fume as per ASTM C 618. It has been observed that square-shaped concrete show very good compressive strength with a manufacturing ratio (as deserved in Concrete Block-III). The compression testing is carried out in a CTM having a capacity equal to 2000 km. For Concrete Block-III, the compressive strength is found to be 39.63 N/mm^2 and 45.58 N/mm^2 for 27 days and 41 days, respectively. The data revealed that when almost 50% cement is replaced with silica fume using fly ash as the base material, a maximum compressive strength can be obtained as represented in Figure 3. This may be attributed to the fact that the addition of silica fume enhances the pozzolanic property in the concrete material.

Split Tensile Strength

The split tensile strength of the concrete is represented in Table 7 with 27 days and 41 days curing period. In such cases, the cylindrical concrete blocks are subjected to CTM for testing the compressive strength; the split tensile strengths of 3.96 N/mm^2 and 4.83 N/mm^2 are obtained for 27 days and 41 days, respectively. There is a remarkable variation in the split tensile strength, which is found to be unusual and keeps on decreasing with an increase in silica fume. For the concrete block (IV) there is a sudden rise in split strength and again

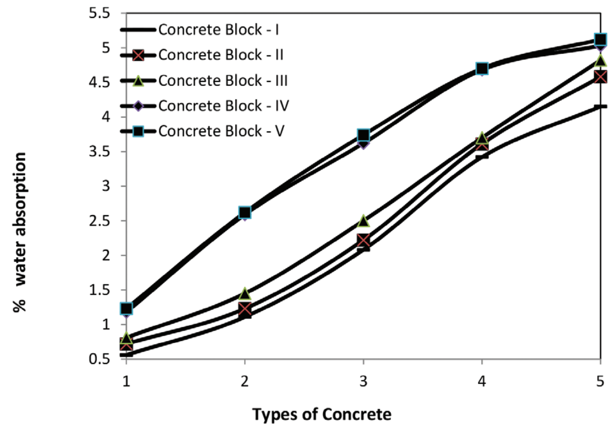

Figure 2: Representing the % of water absorption in the concrete.

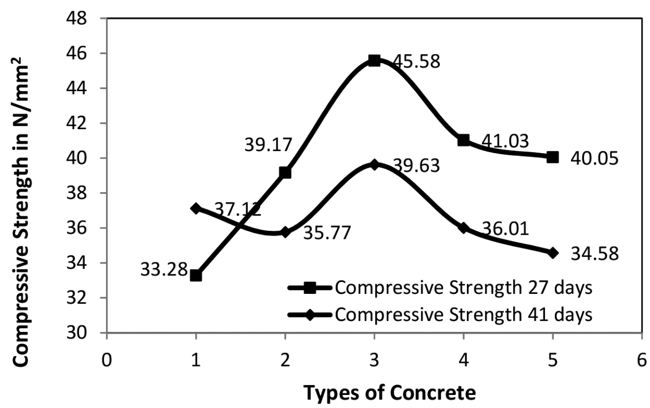

Figure 3: Represents the comparative compressive strength of the concrete materials.

for Block-V, it is reduced. It is being concluded that cylindrical blocks with a cement variation of 4.5% could generate maximum split tensile strength as compared to all other concretes as given in Figure 4.

Flexural Strength

By the addition of silica fume as a replacement for cement and by addition of rice husk ash, various flexural strengths are obtained. Studies are conducted

Table 7: Mechanical properties of the concrete blocks

Mix Design	*Compressive Strength*		*Split Tensile Strength (N/mm^2)*		*Flexural Strength (N/mm^2)*	
	27 days	*41 days*	*27 days*	*41 days*	*27 days*	*41 days*
Concrete Block - I	33.28	37.12	3.76	4.02	5.11	7.07
Concrete Block - II	39.17	35.77	3.85	4.58	5.33	7.48
Concrete Block - III	45.58	39.63	3.96	4.83	6.25	8.05
Concrete Block - IV	41.03	36.01	4.02	4.49	6.23	7.82
Concrete Block - V	40.05	34.58	4.01	4.13	6.18	7.43

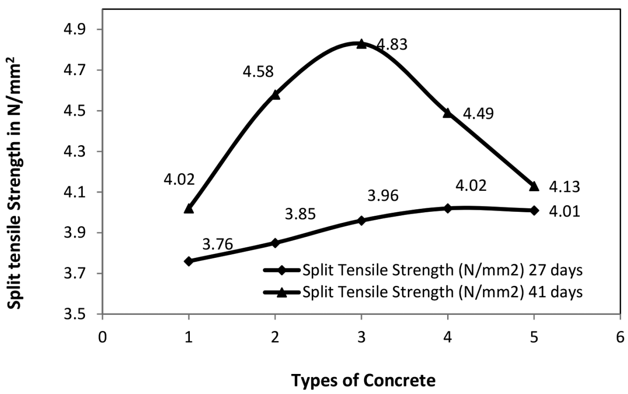

Figure 4: Represents the split tensile strength of the concrete materials.

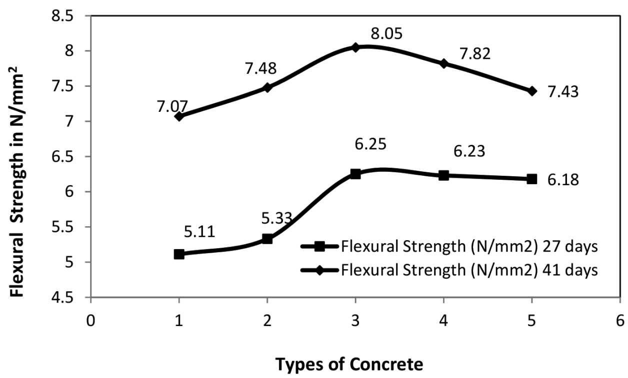

Figure 5: Represents the flexural strength of the concrete materials.

in 27 days and 41 days, respectively, and the results are represented in Table 7. The square-shaped blocks are taken into consideration and are subjected to experiment in a UTM of 500 tonnes capacity. The data revealed that maximum tensile strength is obtained in the case of Concrete Block-III, where for 27 days and 41 days, the values obtained are 6.23 N/mm^2 and 7-82 N/mm^2, respectively, as given in Figure 5.

Conclusion

The study revealed that concrete blocks with very good mechanical strength could be obtained by replacing the cement content of the concrete with silica fume. Furthermore, waste materials such as rice husk ash when added to the concrete mix help to develop hydrophobicity in the concrete. In terms of specific gravity, it has been observed that the specific gravity keeps on increasing with the increase in silica fume substitution in the concrete.

In the case of square-shaped concrete, there is a constant trend of increase in specific gravity. For rectangular blocks, the specific gravity keeps on increasing till silica fume substitution of 8.3%. When the percentage replacement increase from 10.3% to 12.5%, there is a gradual decrease in specific gravity. In the case of cylindrical blocks, with the gradual increase in silica fume, there is a continuous increase in specific gravity. Thus, on the basis of the above data, the rectangular Concrete Blocks are rejected from the test set up and it is concluded that silica fume can be a very good substitute for Concrete Blocks in place of cement.

During verification of the mechanical property, it has been found that the compressive strength of the concrete block with a square shape constitutes the highest compressive strength of 45.58 N/mm^2 when subjected to curing for 41 days.

The data revealed that at every curing period of 21 days, an acceptable strength of 39.63 N/mm^2 could be obtained. In the case of split tensile strength, cylindrical blocks are subjected to study. The result showed that about 4.83 N/mm^2 of split tensile strength could be obtained with a 4.5% replacement of cement. The flexural strength has also been obtained in the range of 6.25 to 8.05 N/mm^2 for 27 days and 41 days of curing, respectively.

References

ACI, 234R-96 (1996) Guide for the Use of Silica Fume in Concrete. Reported by ACI Committee, **234:** 1-51.

Aitcin, P.C., Hershey, P.A. and Pinsonneault (1981). Effect of the addition of condensed silica fume effect on the compressive strength of mortars and concrete. *American Ceramic Society*, **22:** 286-290.

Antonovich, V. and S. Goberis (2003). The effect of different admixtures on the properties of refractory concrete with Portland cement. *Mater. Sci*., **9:** 379-383.

ASTM (2012). Standard Specification for Portland Cement.

Bayasi, Z. and J. Zhou (1993). Properties of silica fume concrete and mortar. *ACI Materials Journal*, **90(4):** 349-356.

Dash, S.K., Kar, S.K. and B.B. Kar (2018). Effect of sand addition on mechanical property of pervious concrete. *IJEP*, **38(2):** 134-141.

Gupta, B.L. and A. Gupta (2012). Concrete technology. Standard Publishers Distributors.

IS 456:2000. Plain and Reinforced Concrete July 2000 ICS 91.100.30

Jallo, E.K. (2012). Experimental study on the behaviour of high strength concrete with silica fume under monotonic and repeated compressive loads. *Al-Rafidain Engineering Journal*, **20(2):** 146-151.

Kadri, E.H. and R. Duval (1998). Influence of silica fume on the workability and compressive strength of high performance. *Concrete Cement and Concrete Research*, **28(4):** 533-547. doi:10.1016/S0008-8846(98)00010-6

Kumar, A., Kumar, A., Kumar, A., Mittal, H. and R. Bhardwaj (2012). Software to estimate spectral and source parameters. *International Journal of Geosciences*, **3(5):** 1142-1149.

Kumar, A., Kumar, A., Gupta, S.C., Mittal, H. and R. Kumar (2013). Source parameters and f_{max} in Kameng Region of Arunachal Lesser Himalaya. *Journal of Asian Earth Sciences*, **70-71:** 35-44.

Kumar, A., Kumar, A., Gupta, S.C., Jindal, A.K. and V. Ghangas (2014). Source parameters of local earthquakes in Bilaspur Region of Himachal Lesser Himalaya. *Arabian Journal of Geoscien*ces, **7(6):** 2257-2267.

Mittal, H., Kamal, Kumar, A. and S.K. Singh (2013). Estimation of site effects in Delhi using standard spectral ratio. *Soil Dynamics and Earthquake Engineering*, **50:** 53-61.

Sakr, K. (2006). Effects of silica fume and rice husk ash on the properties of heavy weight concrete. *Journal of Materials in Civil Engineering*, **18(3):** 367-376.

Yogendran, Y., Langan, B.W., Haque, M.N. and M.A. Ward (1987). Silica fume in high strength concrete. *ACI Materials Journal*, **84(2):** 124-129.