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FLEXURAL STUDY ON SLAB SPECIMENS WITH PARTIAL TO FULLY REPLACEMENT OF NATURAL COARSE AGGREGATE BY COLD BONDED SILICA FUME AGGREGATE

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ABSTRACT - *This study investigates the usage of artificial aggregates made with silica fume, which is a by-product of the reduction of high purity quartz with coal in electric furnaces in the production of Silicon and ferro Silicon alloys in the form of fine powder. An attempt is made to produce Cold bonded Silica Fume Pellets by agglomeration technique, which is a light weight aggregate. The usage of Silica fume aggregate in concrete as a partial replacement of natural aggregate has been examined. The concrete so produced is light weight in nature and the development of such concrete with cold bonded pelletized Silica fume aggregates is to minimize the conventional aggregate which results in protection of natural environment with the replacement of natural aggregate by (0%, 20%, 50%, 75%, and 100%) silica fume aggregate. The effect on strength properties such as compressive strength of cubes, moment carrying capacity and strain energy stored in slabs due to flexure are studied.*

Key Words: *Cold bonded silica fume pellets, light weight aggregate, strain energy, moment carrying capacity.*

I. INTRODUCTION

Concrete is a composite material made from cement, water, coarse aggregate and fine aggregate. The usage of concrete in global societies is after to water. Coarse aggregate is more essential in concrete which is used as a fixer material in higher ratio. In order to reduce the use of natural aggregates from natural resources and energy preservation, the use of silica fume aggregates in concrete is an interesting solution. Researchers carried out an extensive work on this area. In Present study, coarse aggregates from waste materials like silica fume are used with lime and little quantity of cement as binder. An attempt has been made to produce artificial coarse aggregate which is also light weight in nature. The silica fume is a by-product from electrical furnace. One of the essential requirements for green building is to use eco friendly building materials such as industrial waste by- product like silica fume which will also lead to a range of economic and environmental benefits.

1.1 Light Weight Aggregate

Light weight aggregates can be divided into following categories

- Naturally occurring materials such as pumice, foamed lava, volcanic tuff and porous lime stone.
- Naturally occurring materials which require further processing such as expanded clay, shale and slate, vermiculite etc.,
- Industrial by-products such as sintered pulverized fuel ash, foamed or blast furnace slag, hematite, silica fume etc., which are produced either by expansion or agglomeration.

1.2 Light Weight Concrete

One of the disadvantages of conventional concrete is its high self weight. Density of normal concrete is in the order of 2200 to 2600Kg/m^3. This heavy self weight will make it to some extent an uneconomical structural material. Attempts have been made and light weight aggregate concrete has been introduced whose density varies from 300 to 1850Kg/m^3.

II. LITERATURE REVIEW

Chi et al.(2003) [1] used three types of cold bonded cement based fly ash aggregates for the production of concrete. The study indicates that type of light weight aggregates and water to binder ratio are the significant factors influencing strength of concrete.

In their work **Hari Krishnan and Ramamurthy, 2006 [2]** used Pelletization process to manufacture light weight concrete aggregates. Some of the parameters need to be considered in their work for the efficiency of the production of pellets are speed of revolution of pelletizer disc, moisture content, and angle of pelletizer disc and duration of Pelletization.

Owens, P.L. et.al.[3] stated that Light weight aggregate concrete has been used for structural purposes since the 20th century. The Light weight aggregate concrete is a material with low unit weight and often made with spherical aggregates. The density of structural Light weight aggregate concrete typically ranges from 1400 to 2000 kg/m³ when compared with that of about 2400 kg/m³ for normal weight aggregate concrete.

Sidaramapa and Architha [4] studied the flexural behaviour of RCC slab and Ferro cement slabs for cyclic loading. The first crack and collapse load along with their deflections are measured during testing. On comparison Ferro cement slabs are more ductile when compared to RCC slabs for same moment and flexural behaviour.

In their work **V.Bhaskar Desai and A. Sathyam [5]** studied about the different percentages of constituent materials in pelletized aggregate and their different properties and they compared with those of natural aggregates.

From the brief literature study conducted here it appears that very little work is reported in the literature about the study of flexural properties through slab specimen using silica fume aggregate replacing natural aggregates in different proportions. Hence the present study has been undertaken.

III. MATERIALS USED

The following materials are used for preparing the concrete mix. Properties of constituent materials are mentioned in table 1.

1) **Cement** **:** Ordinary Portland cement of Acc cement of 53 grade is used.
2) **Fine aggregate (Sand):** Locally available river sand from Chitravathi river near Battalapally which passing through 4.75mm IS sieve is used which conformed to grading zone-II of IS: 383-1970**[6]**.
3) **Conventional Coarse aggregate:** Crushed granite aggregate conforming to IS: 383-1970**[6]** consisting 20mm maximum size of aggregate has been obtained from the local sources.
4) **Artificial coarse aggregate** (i.e., *Silica fume aggregates(cold bonded*))

Silica fume aggregates = Silica fume + Lime + Cement + Water (by cold bonded Pelletization)

Silica fume: Silica fume is a by-product of the reduction of high purity quartz with coal in electrical furnaces in the production of silicon and Ferro silicon alloys. Before 1970's nearly all silica fume was discharged into the atmosphere. After environmental concern it necessitated the collection and land filling of silica fume but it became economically justified to use silica fume in various applications. Silica fume is procured from *Astrra chemicals, Chennai*. It is a very reactive and effective pozzolanic material due to its fine particle size and high purity of Sio_2 (99.8%) content. It enhances the mechanical properties, durability and constructability in concrete. It helps in protection of steel from rusting and corrosion and increases the life of the structure.

Lime: locally available lime is used as another binder.

Pelletizing Process: the desired grain size distribution of an artificial light weight aggregate is done by means of agglomeration process. The Pelletization process is to manufacture light weight coarse aggregate. Some parameters need to be considered for efficiency of production of pellets are speed of revolution of pelletized disc, moisture content, angle of pelletizer disc and duration of Pelletization. In the cold bonded method increase of strength of pellets by increasing the silica fume, lime & cement ratio by weight. Moisture content and angle of drum parameter influences the size growth of pellets. The dosage of binding agent is more important for making silica fume balls. Initially some percentage of water is added to the binder and remaining water is sprayed during the rotation period because while rotating without water in the drum silica fume and binder (lime & cement) tend to form lumps and does not increase the particle size. The pellets are formed approximately in duration of 6 to 7minutes. The cold bonded silica fume pellets are hardened by normal water curing method for 28 days. The setup of the machine for manufacturing silica fume aggregates is as shown in plate 1, and silica fume aggregates are in plate 2. The percentage proportion adopted for formation of pellets is 47:47:6 i.e., silica fume: lime: cement.

Plate1. Pelletization Machine

Plate 2. Pelletized Silica fume aggregate

5) **Steel:** Fe 415 HYSD bars@ 10mm are placed at 130 mm spacing in both direction of the slab. The yield strength of steel bars is 250N/mm^2. Steel reinforcement details are shown in plate 3.
6) **Water:** locally available potable water which is free from acids, organic substances has been used in this work for mixing and curing.

Table 1: Properties of constituent materials in M20 grade concrete.

S. No	Name of the material		Properties of the material	
1	OPC – 53 GRADE		Specific gravity	3.26
			Initial setting time	50 minutes
			Final setting time	460 minutes
			Fineness	5%
			Normal consistency	30%
2	Fine aggregate passing through 4.75 mm sieve.		Specific gravity	2.54
			Fineness modulus	2.75
3	Coarse aggregate passing through 20-10mm sieve	Natural aggregate	Specific gravity	2.60
			Fineness modulus	6.63
			Bulk density compacted	1620Kg/m^3
		Silica fume aggregates	Specific gravity	2.18
			Fineness modulus	5.80
			Bulk density	854kg/m^3
			Water absorption	>20%
			Shape	Round
4	Steel		Yield strength	415 N/mm^2

IV. EXPERIMENTAL PROCEDURE

An experimental study has been conducted on concrete with volumetric % replacement (0, 25, 50, 75,100) of conventional coarse aggregate i.e., granite by light weight aggregate i.e., by silica fume aggregates. The experimental investigation has been carried out by casting 3 numbers of cubes (150*150*150mm) for compressive test and 3 numbers of reinforced slab specimens (600*600*50mm) to calculate moment carrying capacity and strain energy stored in slabs after 28 days of curing for each proportion. The slabs were white washed for easy identification of cracks patterns and placed on experimental setup platform for testing. The slabs are tested under simply supported condition with uniformly distributed load.

4.1 Casting of specimens

Mix design

The M_{20} concrete mix is designed using ISI method i.e., IS 10262-2009**[7]** and IS 456-2000**[8]** which gives a mix proportion of 1:1.58:2.88 with constant water cement ratio of 0.5. Five different mixes have been studied which are designated as follows,

Table 2: Designation details of specimen

S.No	Name of the Mix	% volume of natural coarse aggregate and silica fume aggregate		No. of specimen cast and tested	
		Natural aggregate	Silica fume aggregates	Cubes	Slabs
1	A-0	100	0	3	3
2	A-25	75	25	3	3
3	A-50	50	50	3	3
4	A-75	25	75	3	3
5	A-100	0	100	3	3
		Total specimens		**15**	**15**

Mixing, Casting and curing of specimen

To proceed with experimental program initially steel moulds were cleanly brushed with mechanical oil on all inner faces to facilitate easy removal of specimens afterwards. For slab specimens two- L shaped frames with depth of 50mm were connected to a flat plate at the bottom using nuts and bolts. Cross-stiffeners were provided at the bottom for flat plate to prevent any possible deflections while casting. The gaps were effectively sealed by using thin card boards and wax to prevent any leakage of cement sand slurry in slab specimen. The moulds are shown in plate 4. After applying the mechanical oil to the steel mould, 10mm thick cover blocks were placed and a mat of 10mm steel rods @130 mm/cc was kept at the bottom of the mould. First fine aggregate and cement were added and mixed thoroughly and then the conventional coarse aggregate with partially replaced pre soaked silica fume aggregates were mixed with them. All of these were mixed thoroughly with hand mixing. Each time 3no of cubes and 3no.of slabs are casted. Castings are shown in plate 5.For all test specimens, moulds were kept on the platform and the concrete was poured into the mould in three layers. Each layer was compacted thoroughly with tamping rod and then the specimens were placed on vibration table for 6-7sec to avoid honey combing. However specimens were de-moulded after 24hrs of casting and were kept immersed in a clean water tank for curing. After 28 days of curing the specimens were taken out of water and were allowed to dry under shade for few hours and then they were white washed on both sides for clear visibility of cracks during testing. The specimens were tested under simply supported condition and under uniformly distributed load.

Plate 3: reinforcement details

Plate 4: Slab specimen with motor

Plate 5: Casting of slab

V. TESTING

5.1 Compressive strength for Cubes

The cubical specimen was placed vertically between the platens of the compressive testing machine. The load was applied gradually without shock and continuously at the rate of 140 kg/ cm^2/ sec till the specimen fails and ultimate loads were recorded. These ultimate loads divided by the area of the specimen gives the compressive strength of each cube. Cube under compression testing machine is shown in plate 6. The test results are furnished in table 3 are graphically presented in figure 1.

Table 3: Cube Compressive Strength Results.

CUBE COMPRESSIVE STRENGTH						
S. No	Name of the mix	Percentage volume replacement of coarse aggregate (%)		Ultimate load(KN)	Cube Compressive Strength in (N/mm^2)	Percentage decrease of Compressive Strength (%)
		Natural aggregate	Silica Fume Aggregate			
1	A-0	100	0	867.00	38.50	0
2	A-25	75	25	832.67	37.00	3.89
3	A-50	50	50	793.00	35.24	8.46
4	A-75	25	75	676.00	30.04	21.97
5	A-100	0	100	609.33	27.08	29.66

5.2 Flexure Test for Slabs

Structural loading frame and platform

The loading frame is designed with beam and column element. The loading platform consists of 4 welded steel beams of ISLB150 in square shape, which is supported on 4 columns of ISLB 150 placed at four corners. The loading platform and loading frame are stiff enough to support the loading without significant deformation. Here, loads will act vertically from the top and its self weight is also considered. Detailing, structural design of steel members and connections were done according to IS 800-1984**[9]**.

Application of loads and loading sequence

The loading arrangement to test the slab specimen under flexure is as follows. The slab specimen is placed simply supported over the clear span of 470mm. The specimen is checked for its alignment in both longitudinal and lateral direction and adjusted if necessary. The beams are designed for maintaining stability of spreader and safety of persons conducting testing. The load is applied with hydraulic jack on the specimen, using 25 tons pre-calibrated proving ring at regular intervals. The load is transmitted to the specimen through I-sections placed over the slab and load is uniformly distributed over the slab through specially manufactured setup with series of iron balls welded to an iron plate placed over the slab specimen in the inverted position as shown in plate.7. Four deflectometers or dial gauges with a least count of 0.01mm are placed at the bottom of the slab. For each increment of loading the deflection at the centre of the span and along four diagonal directions is recorded using dial gauges. Continuous observations are made at different levels. As the load is increased the cracks are widened from bottom and extended to top and finally the specimen fails. At this stage load is recorded as the ultimate load. The test setup of slab is shown in plate 7.

Plate 6: Compression testing machine

Plate 7: Slab testing machine.

Making use of above data, bending moment has been calculated as follows.

Moment carrying capacity at First Crack load and Ultimate loads based on IS code method

According to IS code method (IS 456-2000, clause D-2.1**[8]**) moment carrying capacity is calculated by using following formula.

Moment carrying capacity $\boldsymbol{M = W * \alpha_x * L_x^2}$

For simply supported condition $\boldsymbol{\alpha_x}$ **= 0.062** (Moment coefficient from IS 456-2000, clause D-2.1 from table 27)**[8]**.

M= Bending moment, W= ultimate load, L_x = Effective length of slab

The results are tabulated in table 4 below and shown in fig 2, 3, 4, 5.

Moment carrying capacity at First crack load and Ultimate loads based on Yield line theory

According to Yield line theory, Moment carrying capacity of slabs under simply supported condition is calculated by using following formula derived from the combined process of virtual work done and equilibrium method. For simply support condition,

$\boldsymbol{M = \frac{WL^2}{24}}$ Where W = Collapse load, L = length of slab

Strain Energy Stored in Slabs

The energy absorption is defined as the area under the load deflection curve. The values are determined from test results and are presented in table 4 and graphically shown in figure 4, 5.

Table 4 Moment carrying capacity and strain energy stored in slabs.

Mix	At First Crack			At Ultimate			
	Load (KN)	Moments(KN-m)		Load (KN)	Moments(KN-m)		Strain energy stored (KN-mm)
		IS method	Yield line theory		IS method	Yield line theory	
A-0	26.355	2.237	1.789	148.848	12.637	10.107	258.13
A-25	25.104	2.1314	1.704	121.355	10.303	8.240	240.78
A-50	22.605	1.919	1.534	101.97	8.658	6.924	185.82
A-75	18.855	1.600	1.280	91.355	7.756	6.203	144.94
A-100	16.355	1.388	1.11	78.855	6.695	5.354	112.14

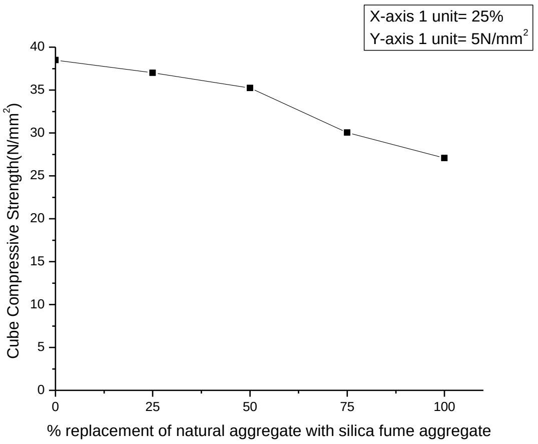

Fig 1: Cube Compressive Strength

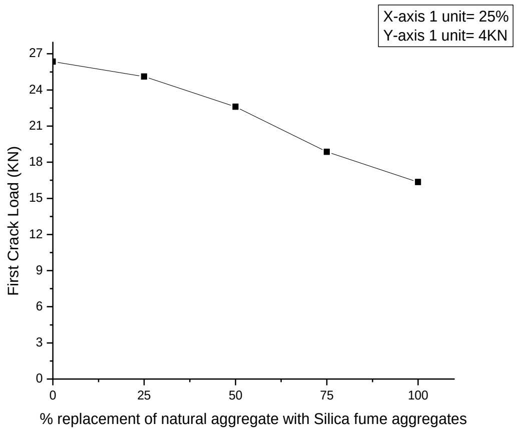

Fig 2: First crack load Vs percentage replacement of silica fume aggregates

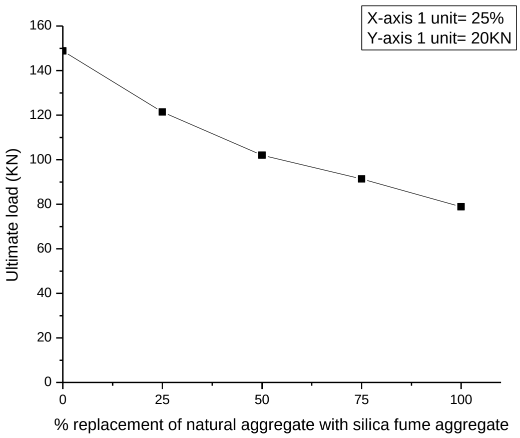

Fig 3: Ultimate load Vs percentage replacement of silica fume aggregates

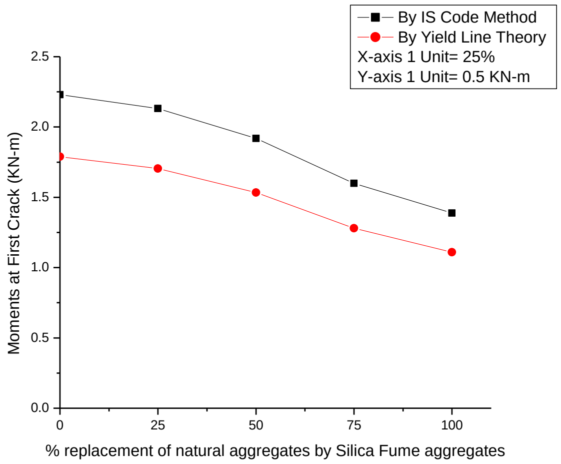

Fig 4: Super imposed variation of moments at first crack Vs percentage replacement of silica fume aggregates

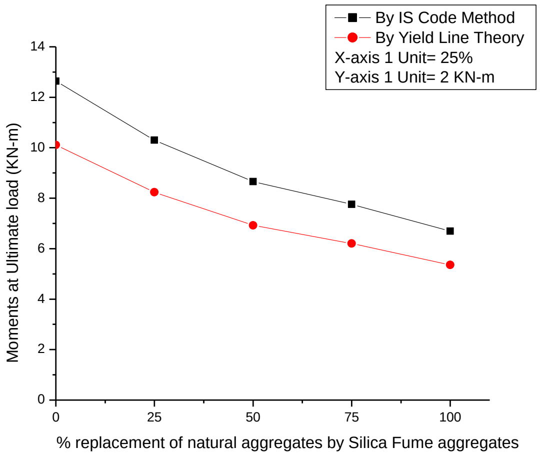

Fig 5: Super imposed variation of moments at ultimate load Vs percentage replacement of silica fume aggregates

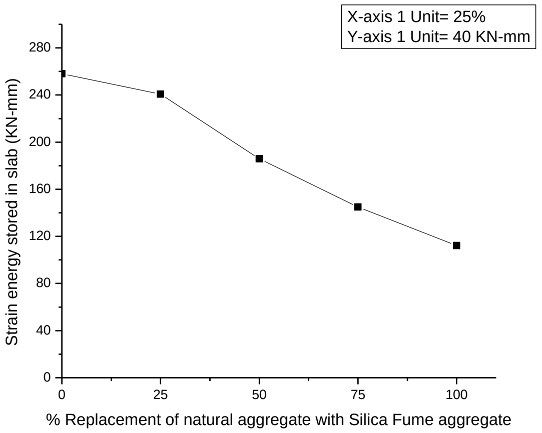

Fig 6: Strain energy stored in slabs

VI. DISCUSSION ON TEST RESULTS

6.1 Influence of silica fume aggregates on cubes compressive strength

The cube compressive strength versus percentage replacement of natural aggregate with silica fume aggregate for 28 days curing period are shown in fig 1. It is observed that with the addition of silica fume aggregate, the cube compressive strength decreases continuously up to 100% replacement of natural aggregate by silica fume aggregate. The target mean strength of M_{20} concrete i.e., 26.6 N/mm^2 has been achieved even when the natural aggregate is replaced with 100% silica fume aggregate as tabulated in table 3 i.e., 27.08N/mm^2. From fig 1 it is observed that as the percentage of silica fume aggregates increases from 0 to 100 % the cube compressive strength decreases from 38.5 to 27.08 N/mm^2.

6.2 Influence of silica fume aggregates at first crack load in slabs

Variation between loads and percentage replacement of natural aggregate with silica fume aggregates are shown in fig 2, and also mentioned in table 4. It is observed that first cracks loads decreases from 26.355 to 16.355KN.

6.3 Influence of silica fume aggregates at ultimate load in slabs

Variation between ultimate load and percentage replacement of natural aggregate with silica fume aggregate are shown in fig 3, and also mentioned in table 4. It is observed that ultimate loads are also decreasing from 148.848 to 78.855KN with the increasing percentage of silica fume aggregates.

6.4 Influence of silica fume aggregates on moments at first crack in slabs

Moments at first crack are calculated by two methods i.e., by IS code method and Yield line theory method. Super imposed variation between moments and percentage replacement of natural aggregate by silica fume aggregates at first crack are shown in fig 4, and also tabulated in table 4. By using IS code method, it is observed that moment carrying capacity at first crack decreases from 2.237 to 1.388 KN-m. Similarly from yield line theory, it is observed that moment carrying capacity at first crack load decreases from 1.789 to 1.11KN-m with the percentage increase of silica fume aggregate from 0 to 100%. The moments calculated from IS code method are higher than those calculated using yield line method.

6.5 Influence of moments on silica fume aggregates in slabs at ultimate load

Moments at ultimate load are calculated by two methods i.e., by IS code method and Yield line theory. Super imposed variation between moments at ultimate load and percentage replacement of natural aggregate by silica fume aggregates are shown in fig 5 and also tabulated in table 4. By using yield line theory, it is observed that moment carrying capacities at ultimate loads are decreasing from 10.107 to 5.354 KN-m. Similarly, from IS code method, moment carrying capacity at ultimate loads is decreasing from 12.637 to 6.695KN-m with the percentage increase of silica fume aggregate from 0 to 100%. Here also it is observed that moments calculated through IS code method are higher than those calculated using yield line theory.

6.6 Influence of silica fume aggregates on strain energy stored in slab

With increase in percentage replacement of natural aggregate by silica fume aggregate, the strain energy stored in slabs decreases continuously up to 100% i.e., 258.13 to 112.14 KN-mm. The variation between strain energy stored and percentage replacement of silica fume aggregate is shown in fig 6 and also tabulated in table 4.

VII. CONCLUSIONS

- From the experimental investigation, it is observed that the production of structural light weight aggregate concrete from cold bonded pelletized silica fume aggregate is possible.
- Silica fume aggregates are lighter and porous in nature; having bulk density around 854Kg/m^3 which is lesser than that for conventional aggregate and hence it is light weight aggregate.
- Cold bonded silica fume aggregates are spherical in shape and hence it improves the workability of concrete with lesser water content when compared to conventional concrete.
- From this study, it is concluded that compressive strength decreased continuously with the increasing silica fume aggregate content in concrete.
- Moment carrying capacity of slabs calculated at first crack load and ultimate loads, as per IS code method is higher when compared with those calculated using Yield line theory.
- With increasing percentage of silica fume aggregates in concrete, the deflections in slabs are found to be increased.
- Since silica fume aggregates shows results comparable with natural coarse aggregate, as the natural aggregate is in the depletion, silica fume aggregates can be considered as replacement material for coarse aggregate. The obtained material can be considered for various applications.

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