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An Experimental Investigation on Silica Fume Blended Cement Mortar with Stone Dust as a Fine Aggregate

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ABSTRACT

The unabated escalation in the cost of cement provided an impetus for finding an alternative, because the Portland cement is an energy intensive material. The Ordinary Portland cement may not be ready to satisfy the requirements of present day's construction filed. The above needs necessitated the development of a new and cheaper material that can fully or partially replace cement in Civil Engineering Constructions. In light of a continuous research, many pozzolanic materials are introduced to the construction field and are well received by the construction industry. Some of the industrial by–products possessing pozzolanic properties are paid attention by the researchers. The disposal problem of huge quantities of industrial wastes encouraged the interest of enthusiastic researchers. The Fly Ash and Condensed Silica Fume belongs to this category. The Fly Ash has already proved its efficiency as a pozzolanic material. Condensed Silica Fume (CSF), a recently introduced pozzolana, gained its importance in construction field within a very short span of time. A lot of research is still being continued in many other countries and the CSF is proved to be an effective pozzolanic material. The quantity of CSF available as a by–product differs from Industry to Industry.

Keywords: Condensed Silica Fume, Compressive strength, w/binder ratio, Workability, Pozzolana, Fine aggregate (stone dust), Water)

I. INTRODUCTION

At the outset of cement history, pozzolanic materials play an emphatic role in altering the properties of cement. Each pozzolana has its own desirable characteristics when used in conjunction with cement. Unless the behaviour of a pozzolana is fully known, it should not be recommended as an admixture to the cement concrete and mortar.

In this pursuance, the researchers met with some industrial by-products, which offer significant technical, economical and ecological benefits when used in the concrete industry. Pozzolana can be incorporated into mortar/concrete in two different ways; one approach is to use it at the manufacturing plant, and the other is to use as a mineral admixture for preparation of mortar/concrete. The blast furnace slag belongs to the first category and the fly ash and condensed silica fume belong to the second.

Condensed Silica Fume, abbreviated as CSF, is a by-product of the Ferro–Silicon alloys or silicon metal industries. In 1981, the world production of CSF was estimated to be 1 million metric tons with about 120,000 tonnes each from the leading producers, Norway and the United States. The production of CSF may be enhanced in future owing to the rapid change in the status of steel industry in many countries of the world.

In 1950, the first experiments were conducted on the use of CSF as a pozzolana in Norway. An extensive research is still continued in Norway and North America. The higher pozzolanic potential of CSF solved the disposal problem and provided better environment at the manufacturing plants.

II. METHODS AND MATERIAL

1. CSF as a pozzolanic material

Condensed Silica Fume (CSF) is "an industrial by– product in the manufacture of silicon metal or silicon alloy, which contains more than 80 % of extremely fine particles of silica in non – crystalline state". The average diameter of particles is about 0.1μm. This product is an excellent admixture to replace the cement in mortar and concrete.

The very fine particles of amorphous silica collected in bag– house filters from the flue gases of silicon or ferro silicon furnaces have been called by various names, such as silica dust, silica flour, micro silica, aerosol, volatilized silica, Pyrogenic silica, silica fume and condensed silica fume.

Nomenclature of CSF

It was suggested that the term CSF should be prefixed to define the exact source of material.

Ex: **Source of material CSF available**

1.	Silicon metal	Si – CSF
2.	Ferro Silicon Alloys	FeSi – 90 *– CSF
		FeSi – 75 *– CSF
		FeSi – 50 *– CSF
3.	Ferro – Chromium Silicon-Alloy	FeCr – Si – CSF
4.	Calcium – Silicon alloy	CaSi – CSF
5.	Silicon – Manganese alloy	SiMn – CSF

* The numbers indicates the percentage of silicon in Ferro Silicon alloy.

Stone dust as a fine aggregate

The increase in the cost of river sand is due to dwindling natural resources coupled with the restrictions imposed by several state governments on sand quarrying, as well as the concern to prevent further environmental degradation and conserve ground water. The spiraling costs of river sand used as fine aggregate in concrete have increased the cost of construction significantly in the past two decades. These problems have led to the search for alternative materials for fine aggregates that are eco-Sfriendly besides being inexpensive.

Stone dust, a waste product at stone crushing units, is available in large amount and the viable use of such a large amount of stone dust is of most importance in making mortar / concrete since stone dust is found to act as an inert filler material in concrete. Stone crusher dust, which is available abundantly from crusher units at a low cost in many areas, provides a viable alternative for river sand.

2. Experimental Study

Generally, addition of pozzolanas provides many technical advantages. The CSF offers superior properties than any other pozzolana like fly ash owing to its extreme fineness and chemical composition.

Merits of CSF as a pozzolana

1. Addition of CSF reduces the segregation and bleeding tendencies because the fine particles of CSF occupy the space between the cement grains.
2. Unlike the other by-product pozzolanas, such as fly ash, a unique feature of CSF from a single source has little or no variation in chemical composition from one day to the other provided the same raw materials have been used in the production process.
3. Cohesiveness of concrete mix is greatly improved, when CSF is added due to increase in the number of solid – to – solid contact points resulting highly attractiveness for use in shotcreting, pumping and tremie concreting operations.
4. CSF alters the setting times very slightly.
5. CSF lowers the creep of concrete.
6. Ordinary Portland Cement (OPC) shows much improved compressive strength at early ages when blended with CSF.
7. CSF significantly reduces the permeability of concrete or mortar which is useful in concrete dam construction.
8. The long term drying shrinkage of OPC is slightly increased with increase in percent replacement of CSF.
9. The freezing and thawing resistance of concrete containing CSF is better when compared to plain concrete.
10. The abrasion resistance of OPC concrete can be enhanced by adding CSF.

11. The resistance of concrete to aggressive acidic and sulphuric waters is greatly improved when CSF is added.
12. The alkali – aggregate reaction in concrete can be prevented with smaller quantities of CSF than any other pozzolana.
13. CSF concrete prevents the chloride penetration and reduces the chloride induced corrosion.
14. The rate of strength development can be accelerated by using CSF in fly ash concrete and slag concrete.

Demerits of CSF

1. It increases the plastic shrinkage of cement concrete which can be eliminated by proper curing.
2. Air – entrainment in concrete is a big problem and requires high percentages of air – entraining admixture.
3. It is difficult to handle and transport the CSF material.
4. There is little health hazard potential from the inhalation of amorphous silica in CSF.
5. Quality control is extremely important with respect to minimizing product variation due to changes in material fineness and CSF product forms.

1.4 Stone dust as a fine aggregate

The increase in the cost of river sand is due to dwindling natural resources coupled with the restrictions imposed by several state governments on sand quarrying, as well as the concern to prevent further environmental degradation and conserve ground water. The spiraling costs of river sand used as fine aggregate in concrete have increased the cost of construction significantly in the past two decades. These problems have led to the search for alternative materials for fine aggregates that are eco-friendly beside being inexpensive.

Stone dust, a waste product at stone crushing units, is available in large amount and the viable use of such a large amount of stone dust is of most importance in making mortar / concrete since stone dust is found to act as an inert filler material in concrete. Stone crusher dust, which is available abundantly from crusher units at a low cost in many areas, provides a viable alternative for river sand.

3. Materials

The following materials are used for the present investigation to prepare the test specimens.

- ✓ 53 grade Ordinary Portland Cement – Penna power,
- ✓ Condensed Silica Fume (CSF)
- ✓ Stone dust,
- ✓ Water.

Cement

A 53 grade Ordinary Portland Cement (OPC) is used for the present investigation. The properties of cement used are presented in Table 1

Sl. no.	Property	Results	IS: 12269 Recommendations
1	Fineness of cement (%) (Residue on 90 μ I.S. Sieve)	2.67	< 10
2	Standard consistency (%)	33.00	
3	Setting times :		
	a) Initial setting time (min)	95	> 30
	b) Final setting time (min)	280	< 600
4	Specific gravity	3.158	
5	Compressive strength (N/mm2) at		
	a)3 days	27.30	> 27.0
	b)7 days	38.00	> 37.0
	c) 28 days	53.30	> 53.0

Condensed Silica Fume

A typical CSF available at FOSROC Chemicals (India) Pvt., Ltd., and Bangalore is used for the experimentation. The physical and chemical properties of CSF are furnished in Table 2.

Sl. no.	Characteristics Recommendations	Results	IS: 1344 - 1968 Recommendations
1	Colour	Light grey	-
2	Specific gravity	2.051	-
3	Specific surface (cm^2/gm)	140000-160000	3200 (max)
4	Bulk density (kg/m^3)	200	-
5	pH of water extract	8.5	-
6	Compressive strength of pozzolana – cement mortar (percentage of the strengthof plain cement mortar cubes) when tested according to IS : 1727 – 1967		
	at 28 days	123.94	80 (min)
	at 90 days	141.82	100 (min)

Fine aggregate (stone dust)

The stone dust used in the investigation is obtained from the crusher at Tanapalli near Tirupati in Andhra Pradesh. 1/3 part of stone dust passing through IS: 2.36 mm. sieve and retained on IS: 1.18 mm sieve, 1/3 part of stone dust passing through IS : 1.18 mm. sieve and retained on IS : 600 μ sieve and balance 1/3 part of stone dust passing through IS : 600 μ. sieve and retained on IS : 90 μ sieve is used for the preparation of test specimens.

The properties of stone dust are presented in Table 3

Sl. no.	Property	Results (%)
1	Specific gravity	2.71
2	Bulk density	15.65 KN/m^3
3	Fineness modulus after sieving	2.80

Water:

Tap water used for the present observations is obtained at S.V. University College of Engineering, Tirupati with pH value of 7.85. The same water is used for mixing and curing of cement mortar cubes and beams.

Experimental set up:

The following equipment is used for casting and testing of the specimens

1. Mechanical mortar mixer according to Indian Standards
2. Jolting apparatus,
3. Cube and bar moulds,
4. Standard length comparator for measuring drying shrinkage,
5. 40T Universal Testing Machine for compressive strength determination,
6. 2.5T Loading Machine for transverse strength determination.

III. RESULTS AND DISCUSSION

The objective of the present investigation is to determine the suitability of Condensed Silica Fume (CSF), obtained as a by-product of Ferro-Silica alloys and silicon metal industries and stone dust, obtained as a waste product from quarry, for use in cement as a partial replacement of cement and complete replacement of sand as fine aggregate. This investigation is also extended to examine the development of compressive and transverse strength of CSF – Cement mortar with stone dust as fine aggregate at different W/Binder ratios.

Specific gravity of CSF – Cement mix

The specific gravity of CSF – Cement blend is determined using Lechatelier flask. The specific gravity is determined upto 25 % replacement by CSF for each 5 % increase in replacement. The results are obtained as the average value of three samples and the results are shown in Table4

Sl. no.	% Replaced by CSF	Specific gravity
1	0	3.158
2	5	3.093
3	10	2.995
4	15	2.903
5	20	2.896
6	25	2.826

Standard or normal consistency of CSF – Cement mix

The normal consistency of partially replaced cement by CSF is determined for percentage replacements of 0, 5, 10, 15, 20 and 25 as per the I.S. specifications. The results are shown in Table 4.3 and the variation of normal consistency of CSF – Cement paste with percentage replacement by CSF is shown in following table5

Sl. no.	% Replaced by CSF	Normal consistency
1	0	33.00
2	5	36.50
3	10	39.00
4	15	41.50
5	20	42.50
6	25	44.00

Setting times of CSF – Cement mix

The initial and final setting times of cement with percent replacement by CSF in percentages of 0, 5, 10, 15, 20 and 25 are determined and the results are furnished in Table 6

Sl. no.	% replaced by CSF	3 days	7 days	28 days	90 days	180 days
1	0	13.67	24.67	33.33	37.00	38.67
2	5	14.00	28.00	34.67	37.67	39.67
3	10	14.67	28.67	36.67	38.67	41.32
4	15	15.67	34.67	43.67	48.33	50.67
5	20	14.33	30.67	42.33	46.67	49.33
6	25	14.00	30.33	37.00	41.67	44.33

Soundness of CSF – Cement mix

The soundness of cement is determined using Lechatelier apparatus for the percent replacements by CSF in percentages of 0, 5, 10, 15, 20 and 25. The soundness of cement is expressed in mm of the expansion of Lechatelier apparatus. Higher expansion indicates that the cement is unsound i.e., it can not resist the volume changes. The average expansions of three specimens are reported in Table 7

Sl. no.	% Replaced by CSF	Expansion of Lechatlier apparatus in mm
1	0	0.98
2	5	0.28
3	10	0.34
4	15	0.42
5	20	0.54
6	25	0.58

Compressive strength of CSF – Cement binder

The compressive strength of cement replaced by CSF is determined with percentage replacements of 0, 5, 10, 15, 20 and 25. The amount of water used for mixing is (p/4 + 3) percent of combined weight of cement, CSF and stone dust, where 'p' is the normal consistency of CSF – Cement blend. The compressive strength of cement is determined at 3, 7, 28, 90 and 180 days. The average values of three tested specimens are reported in Table 8 The variation of compressive strength with percentage replacement by CSF at 3, 7, 28, 90 and 180 days are shown in Fig.

Sl. no.	% replaced by CSF	3 days	7 days	28 days	90 days	180 days
1	0	13.67	24.67	33.33	37.00	38.67
2	5	14.00	28.00	34.67	37.67	39.67
3	10	14.67	28.67	36.67	38.67	41.32
4	15	15.67	34.67	43.67	48.33	50.67
5	20	14.33	30.67	42.33	46.67	49.33
6	25	14.00	30.33	37.00	41.67	44.33

Transverse strength of CSF – Cement binder

The transverse strength of cement at 28 days is determined with percentage replacement by CSF in percentages 0, 5, 10, 15, 20 and 25. The W/Binder ratio is 0.50 as mentioned in I.S. specifications. The results are tabulated in Table 9

Sl. no.	% Replaced by CSF	Transverse strength at 28 days (MPa)
1	0	15.000
2	5	16.620
3	10	17.500
4	15	15.500
5	20	14.050
6	25	13.310

Drying shrinkage of CSF – Cement mortar with stone dust as fine aggregate

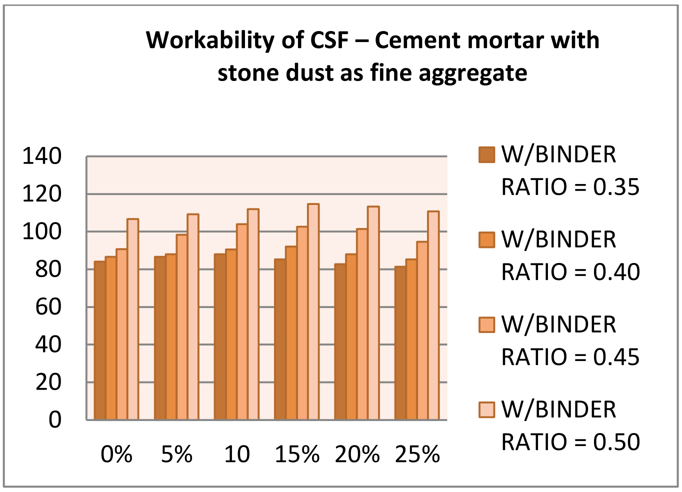
The drying shrinkage of CSF – Cement mortar with stone dust as fine aggregate is determined for percentage replacement by CSF in percentages 0, 5, 10, 15, 20 and 25. The 28 days drying shrinkage of CSF – Cement mortar is expressed as the percentage shrinkage of 250 mm length of mortar bar and results are furnished in Table 10

Sl. no.	% Replaced by CSF	Drying shrinkage (%)
1	0	0.012
2	5	0.024
3	10	0.032
4	15	0.040
5	20	0.062
6	25	0.073

Workability of CSF – Cement mortar with stone dust as fine aggregate

The workability of CSF – Cement mortar with stone dust as fine aggregate is represented by % flow of mortar, determined using 'Flow table apparatus'. The workability of CSF – Cement mortar is determined for the percent replacements of 0, 5, 10, 15, 20 and 25 with W/Binder ratio of 0.35, 0.40, 0.45 and 0.50. The % flow of CSF – Cement mortars are tabulated in Table 11.

% replaced by CSF	W/Binder=0.35 (% flow)	W/Binder=0.40 (% flow)	W/Binder=0.45 (% flow)	W/Binder=0.5 (% flow)
0	84.00	86.67	90.67	106.70
5	86.67	88.00	98.33	109.30
10	88.00	90.50	104.00	112.00
15	85.33	92.00	102.67	114.67
20	82.67	88.00	101.33	113.33
25	81.33	85.33	94.67	110.67



Graph 1 shows workability of CSF-cement mortar with stone dust as fine aggregate

Density of CSF – Cement mortar with stone dust as fine aggregate

The density of mortar is calculated using the weight and volume of the cubes which are used for the determination of compressive strength of mortar in which CSF partially replaced the cement. The percent age replacements by CSF are 0, 5, 10, 15, 20 and 25 and the W/Binder ratio varies from 0.35 to 0.50 with 0.05 increments. The densities of mortar in g/cc are tabulated in

Table 12

% replaced by CSF	W/Binder=0.35 (% flow)	W/Binder=0.40 (% flow)	W/Binder =0.45 (% flow)	W/Binder=0.5 (% flow)
0	2.202	2.217	2.231	2.221
5	2.212	2.221	2.240	2.231
10	2.226	2.250	2.282	2.254
15	2.245	2.278	2.297	2.288
20	2.236	2.254	2.292	2.278
25	2.221	2.245	2.288	2.273

Compressive and transverse strength of 1:3 CSF – Cement mortar at different W/Binder ratios with stone dust as fine aggregate

Another objective of the present investigation is to determine the compressive and transverse strength of 1:3 CSF – Cement mortar at different W/Binder ratios with stone dust as fine aggregate.

Cube moulds and bar moulds

Cube moulds giving 50 sq.cm. Cross sectional area made of metal not amenable to be attacked by cement mortar and satisfying all I.S. codal provisions are used in the present investigation for the determination of compressive strength. The 160mm x 40mm x 40mm bar Moulds are used as described in I.S specifications to determine the transverse strength of mortar.

Mix proportions

The mortar mix 1:3 (binder: fine aggregate) by weight is considered with percentage replacement by CSF in percentages 0, 5, 10, 15, 20 and 25. The compressive and transverse strength of each CSF – Cement mix is determined for W/Binder ratios varying from 0.35 to 0.50 with every 0.05 increment.

Mixing

Mixing is carried out using a mechanical mixer conforming to I.S. specifications. The constituents are first poured in mixer and mixed in dry condition till uniform colour is obtained. Then the water in calculated amount is added to it and mixing is continued till a uniform, homogeneous paste is obtained.

Casting

The test specimens for the determination of compressive strength of mortar are prepared using the standard metallic cube moulds giving a cross sectional area of 50 sq. cm.

Bars for the determination of transverse strength are prepared using standard bar moulds of 40 x 40 x 160 mm size. All moulds were lubricated by applying a very thin layer of oil on the inner surface of the moulds. Fresh mortar was filled in to the moulds and compacted using the vibrating table.

Curing

After the casting of cubes and bars the moulds are kept for air curing for one day and the specimens were removed from the moulds after 24 hours period of moulding of mortar.

Marking has been done on the specimens to identify the percentage of CSF and W/Binder ratio. To maintain constant moisture on the surface of the specimens, they were immersed in water for curing. All specimens have been cured for the desired age.

Testing procedure

The mortar cubes are tested for the compressive strength using a '40T Universal Testing Machine' at the 3, 7, 28, 90 and 180 days. The compressive strength is taken as the average value obtained from three individual test specimens.

The mortar bars are tested for the transverse strength using a '2.5T Loading Machine' at 28 days. The average value of three individual test specimens is obtained as the transverse strength of mortar.

Test results

The cubes are tested at 3, 7, 28, 90 and 180 days and the bars are tested at 28 days. The results are tabulated and the variation of strength with percentage replacement by CSF at different ages is shown for each W/Binder ratio.

The compressive strength of CSF – Cement mortar is reported at different ages for each W/Binder ratio. The strength ratio can be defined as the ratio of the strength of CSF replaced mix to the reference mix and expressed in percentage.

$$strength\ ratio = \frac{srength\ of\ CSF - cement\ motar}{strength\ of\ reference\ mix} X100$$

Strength of CSF – Cement mortar

The gain of compressive strength of CSF – Cement mortar between the ages 3 & 7, 7 & 28, 28 & 90 and 90 & 180 days are shown at different W/Binder ratios. The gain ratio can be defined as the gain of the compressive strength of CSF – Cement mix to that of reference mix and expressed in percentage.

$$Gain\ ratio = \frac{gain\ srength\ of\ CSF - cement\ motar}{gain\ strength\ of\ reference\ mix} X100$$

In Table 13, the gain of strength due to unit replacement of cement by CSF is shown for each W/Binder ratio. The gain of strength due to unit replacement of cement by CSF can be understood as the gain of strength of cement mortar when one percent of cement is replaced by CSF and can be obtained as:

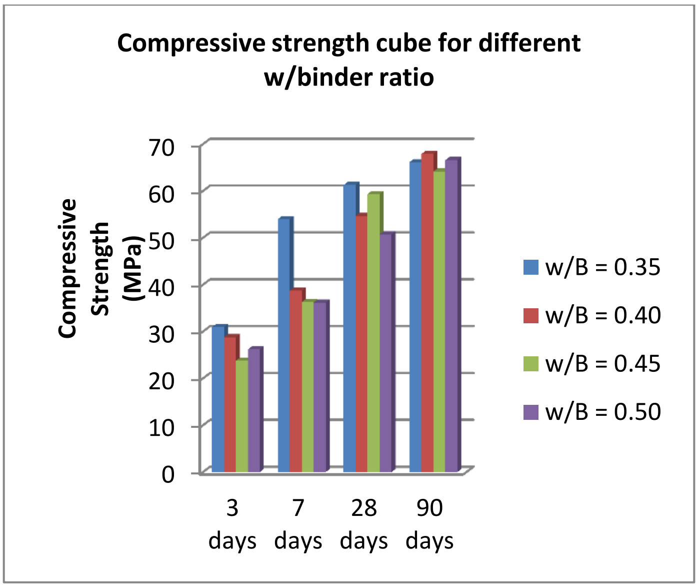
Strength of CSF (CM)– Strength of reference mix
- -
Strength of reference mix X percent replaced / 100

In Table 14, the transverse strength of CSF – Cement mortar at 28 days, the strength ratio and the gain of strength due to unit replacement of cement by CSF is shown for different percentage replacements and for each W/Binder ratio.

Compressive strength cube for different w/binder ratio

Table 13

s.no	W/binder ratio	Compressive % by weight		Compressive Strength (MPa)			
		OPC	CSF	3 days	7 days	28 days	90 days
1	0.35	80	20.0	30.96	54.00	61.29	66.15
2	0.4	80	20	28.8	38.7	54.68	67.91
3	0.45	80	20	23.76	36.27	59.35	64.14
4	O.50	80	20	26.19	36.18	50.76	66.6

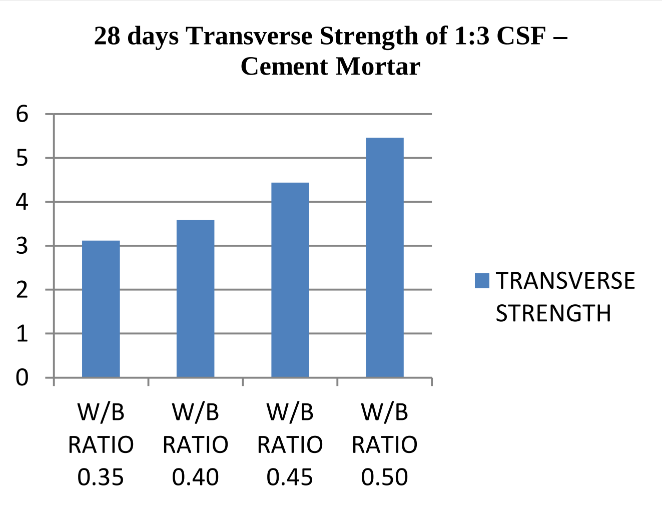


Graph 2 shows that compressive strength cube for for different W/Binder ratio

28 days Transverse Strength of 1:3 CSF – Cement Mortar at different W/Binder ratios

Table 14

Composition on % by weight		w/binder ratio 0.35	w/binder ratio 0.40	w/binder ratio 0.45	w/binder ratio 0.50
OPC	CSF				
0	0	3.216	3.416	3.644	3.877
95	**5**	2.954	3.303	3.758	3.958
90	10	2.962	3.281	3.916	4.209
85	15	3.021	3.34	4.053	4.527
82.5	17.5	3.098	3.437	4.246	5.183
80	20	3.117	3.585	4.44	5.38
77.5	22.5	3.156	3.714	4.403	5.261
75	25	3.134	3.593	4.209	4.774
72.5	27.5	3.02	3.418	3.858	3.769
70	30	2.866	3.181	3.546	3.449



Graph 3 shows that 28 days Transverse strength of 1:3 CSF-cement mortar

The transverse strength increases with increase in percent replacement of cement with CSF and is found maximum at about 10 percent replacement at a W/Binder ratio of 0.45. The transverse strength at 28 days followed the same trend at all W/Binder ratios. The strength ratio is more than the reference mix for CSF replacements of 5, 10 and 15 percent and is less than the reference mix for 20 and 25 percent replacements. The gain of transverse strength due to unit replacement is in general more at about 10 percent replacement for all W/Binder ratios.

IV. CONCLUSION

The CSF available in India needs an extensive research and the suitability has to be checked to use as a pozzolana. The following conclusions are drawn based on the investigation carried out

1. The specific gravity of CSF – Cement mix is decreased with increase in percentage replacement of cement by CSF.
2. The normal consistency of CSF – Cement paste is increased with the increase in the percentage replacement by CSF.
3. The initial setting time is decreased with increase in percentage replacement by CSF. The final setting time of CSF – Cement blend varied very insignificantly with increase in percentage replacement.
4. The soundness of CSF – Cement paste at all percentage replacements is more than that of cement paste. The soundness of CSF – Cement paste is decreased with increase in percentage replacement.
5. The compressive strength of CSF – Cement blend is increased with increase in percentage replacement of cement by CSF up to about 15 and decreases with further replacement of cement by CSF.
6. The 28 days transverse strength of CSF – Cement blend is increases with increase in percentage replacement of cement by CSF up to about 10 and decreases with further replacement of cement by CSF.
7. The 28 days drying shrinkage is increased with increase in percentage replacement by CSF.

8. The workability of CSF - Cement mortar attains a maximum value at a certain percentage of replacement and decreases with increase or decrease in the percentage replacement, for all W/Binder ratios.
9. The maximum density of CSF – Cement mortar is 2.297 g/cc at W/Binder ratio of 0.45 for 15 % replacement of cement by CSF and the minimum is 2.202 g/cc at W/Binder ratio of 0.35 for reference mix.
10. The variation of compressive strength of CSF – Cement mortar with different percentages of replacement of cement by CSF follows the same pattern for different W/Binder ratios at all ages. The maximum compressive strength occurs at about 15 percent of replacement for all W/Binder ratios.
11. The 28 days compressive strength is maximum for all replacements of cement by CSF for W/Binder ratio of 0.40. The maximum value of compressive strength at 28 days is occurring at about 15 percent replacement of cement by CSF for all W/Binder ratios.
12. The compressive strength of the binder (with normal consistency) at 15 percent replacement lies between the compressive strength of CSF – Cement mortar for W/Binder ratios of 0.35 and 0.40.
13. The transverse strength of CSF – Cement mortar is maximum at about 10 percent replacement for a W/Binder ratio of 0.45.

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