THE EFFECT OF SILICA FUME IN COCONUT SHELL CONCRETE AND EXAMINING BOND THROUGH INVERTED METALLURGIC MICROSCOPE

V.R.Prasath Kumar* and K.Gunasekaran

Department of Civil Engineering, SRM Institute of Science and Technology, Tamil Nadu, India

*E-mail: prasathv@srmist.edu.in

ABSTRACT

The use of natural resources in concrete production makes environmental worry. To protect the natural resource one of the possible solutions is to use different generated solid waste. Coconut shell is one of the agriculture waste which is been tried recently as coarse aggregate in concrete production. The cement is partially replaced with silica fume to reduce the emission of carbon dioxide (CO₂). The silica fume was replaced from 5 to 25% in the increment of 5% both in a coconut shell and conventional concrete for the target strength of M25. Compressive strength of all these mixes was conducted at 3, 7, 28, 56, 90, 180 and 365 days for optimization of the percentage of silica fume to be used for its effective usage. It was observed that 10% replacement of silica fume gives higher strength compared to others. The other properties like flexural, split tensile and impact resistance strength were done for the optimized percentage of silica fume at the age of 3, 7 and 28 days. The inverted metallurgical microscope was used to inspect the interfacial transition zone between cement mortar and aggregates. This confirms the bonding layer is inversely proportional to its age.

Keywords: Coconut Shell, Silica Fume, Light Weight Concrete, Mechanical Properties, Inverted Metallurgic Microscope.

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INTRODUCTION

Coconut shell (CS) is actually hard and not easily degradable material is used in concrete which can be a suitable substitute material for coarse aggregate.¹ The author has done enough research work in coconut shell concrete (CSC) and proved to use CS is used in structural works.¹⁻⁶ The author has carried out his work on CSC by replacing cement with silica fume (SF) and fly ash at 5, 10, and 15% separately, in which optimum of 10% was achieved in SF and had better results while comparing with fly ash.⁷ Similarly replacing cement with SF at 10% has proved to gain higher in strength by 10.5% on CSC and 2.7% in conventional concrete (CC) while comparing with their controlled concrete.⁸ The recycled aggregate concrete with steel fibre and its fracture behaviour was investigated with the coupling effect of rubber and silica fume; it is found that the replacement of cement by 10% SF has better results compared to 3% in addition. The 10% SF and 5% rubber is been suggested as the best combination for steel fibre recycled aggregate concrete.⁹ The fineness of SF is blended with cement is used to achieve high strength concrete and high-performance concrete, the SF was grounded to an average particle size of less than 45 micro meters was used.¹⁰ The manufacturing of hollow blocks, solid blocks and paver blocks were done by replacing cement with 25% and 50% of recycled concrete dust and flyash.¹¹ The performance of pervious concrete was improved in addition to styrene-butadiene latex and SF, which increases the strength as well as density.¹² Concrete was produced using 100% recycled aggregate incorporating with mineral admixture say fly ash, metakaolin, paper sludge ash and SF. The experiment was carried out in two methods say addition and replacement method with various proportion level, in which 15% metakaolin, 5% paper sludge ash, 15% fly ash and 10% SF induces the better performance with 100% recycled aggregate concrete.¹³ Behaviour of high performance concrete paste at sea water environment was studied

by replacing cement with SF at 10%. Mixing of SF and murram with fly ash based geopolymer glue results in an economical elite cover even at lower alkalinity.¹⁴ CS were been used in replacing partially with fine aggregate, and the target mean strength of 25.09 N/mm² was achieved by replacing 50% of CS, at the same time on replacing 10% CS with fine aggregate maximum strength of 27.53 N/mm² was obtained.¹⁵ The XRD analysis says that the peak intensity of C₂S and C₃S was higher, the peak intensity of gypsum was relatively low.¹⁶ Foam concrete was prepared by adding SF and fly ash separately, the density was found to increase with SF and compressive strength of 26.8 N/mm² was achieved, which is 83.2% higher than fly ash foam concrete.¹⁷ The SF at 15% added with ground granulated blast furnace slag at 50% yields the 28th-day compressive strength of 41.2 N/mm² in CSC.¹⁸ The worn image wear pattern of alloy and composite sample was studied through an inverted metallurgical microscope (IMM) to find its hardness.¹⁹ The microstructure of the manufactured composite samples was examined using IMM and result was identified to be a uniform distribution of support particles in the matrix.²⁰

EXPERIMENTAL

Coconut Shell

The major ingredient used for the work is CS, coarse aggregate (CA), river sand and silica SF. The CS has very good abrasion properties, good durability and high toughness which is suitable for long-lasting use in concrete. CS is collected from Vellore district in Tamilnadu. The collected CS are well-seasoned and broken into aggregates in the coconut shell crusher which is been installed in SRM Institute of science and technology. The CS is soaked in water and made to saturated surface dry (SSD) condition at room temperature before they are used for casting. This is done because the CS in the purely dry state has the capacity to absorb the water in concrete, so to avoid this action; they are made to a saturated surface dry condition so that their capacity to absorb the water during concrete mixing can be prevented. The CS that are passed through 12mm and retained in 4.75mm sieve is used as CA to prepare the CSC. The properties of CS are given in Table-1.

Aggregates

The fine aggregate (FA) and CA were collected through local vendors, the FA was well sieved to remove the waste and maintained under the size of 4.75mm. The CA is passed through 12mm and retained in 10mm sieve were taken to cast controlled concrete. The selection and test on aggregates were done as per IS383:1970[21]. The properties of coarse, FA and CS are given in Table-1.

Silica Fume(SF)

SF, commonly known as micro silica, is an ultrafine powder composed from the by-product of silicon and ferrosilicon alloy manufacturing and consists of round mote with a mean particle diameter of 150nm. The properties of SF and cement are given in Table-2.

Table-1: Physical and Mechanical Properties of Aggregates

Properties		CS	CA	FA (River Sand)
Size (mm)		4 - 8	10 to 12.5	Less than 4.75
Moisture Content (%)		4.5	-	-
Water Absorption (%)		22	0.3	-
Specific Gravity		1.15	2.84	2.5
Impact Value (%)		8.2	12.5	-
Crushing strength (%)		2.5	6.25	-
Abrasion Value (%)		1.6	1.9	-
Bulk Density in (kg/m ³)	Compacted	650	1620	580
	Loose	550	1450	-
Voids (%)	Compacted	38.12	41.57	-
	Loose	47.65	48.66	-
Fineness Modulus		6.3	6.84	2.54

Table-2: Physical and Chemical Properties of Cement and SF

Mineral Composition	Cementations Materials (%)	
	OPC	SF
CaO	63	1.6
Al ₂ O ₃	1.33	0.4
SiO ₂	21.6	90
MgO	0.7	-
Fe ₂ O ₃	3.7	0.4
Na ₂ O	0.4	0.5
SO ₃	0.88	0.4
K ₂ O	-	2.2
Specific Gravity	3.15	2.2
Specific Surface (cm ² /gm)	2250	15000 - 30000
Colour	Grey	Pure white
Fineness (%)	5	-

Mix Proportion

Indian standard codes are generally used for the mix design in India. But IS codes aren't sufficient enough for an accurate mix design for lightweight concrete. So generally trial and error methods are adopted for getting the better mix design which has been already proved by K. Gunasekaran.² The mix design of 1:2.22:3.66:0.55 was adopted for Controlled concrete and 1:1.47:0.65:0.42 was adopted for CSC. The usually crushed stones are used as CA in conventional cement concrete, whereas saturated surface dried CS is used as CA in CSC. Table-4 indicates the material quantity for both the type of concrete for 1m³. Since this study is about comparing the replacement of cement with SF in both the concretes, hence the CA, FA and water content for both conventional and CSC remains same for all the replacement of cement with SF. The replacement of cement by SF is done on a weight basis. The weight of CA and FA is 1171kg/m³ and 710 kg/m³ for conventional concrete (CC), and for CSC it is 332kg/m³ and 750 kg/m³ in weight for coconut shell aggregate and FA. The water content is 176 litres and 214.2 litres for CC and CSC. The mixed number from SC 1 to SC 6 denotes the various percentage of cement and SF for CC and SCS 7 to SCS 12 denotes the same for CSC. The proportion of materials for 1m³ of concrete is shown in the below Table-3.

Table-3: Material Quantity of CC and CSC

Cement + SF (%)	Material Proportion of for 1m ³					
	CC			CSC		
	Mix No	Cement (kg)	Silica Fume (kg)	Mix No	Cement (kg)	Silica Fume (kg)
100 + 0	SC 1	320	0	SCS 7	510	0
95 + 5	SC 2	304	16	SCS 8	484.5	25.5
90 + 10	SC 3	288	32	SCS 9	459	51
85 + 15	SC 4	272	48	SCS 10	433.5	76.5
80 + 20	SC 5	256	64	SCS 11	408	102
75 + 25	SC 6	240	80	SCS 12	382.5	127.5

Specimen Preparation

The compressive strength was achieved by casting cube of size 100mm x 100mm x 100mm. For the entire test minimum, three samples were tested and the average is given as the result. The density of CC is between 2400 to 2500 kg/m³, and for CSC it is between 1940 to 2000 kg/m³. Slump value was in the range between 10mm to 22mm for CC and 22mm to 35mm for CSC for different mix proportions. Since

the workability was low, table vibrator was used to compact the specimens for all the mixes. The split tensile strength was determined by casting the cylinder of size 100 mm diameter and 200mm in height for both CC and CSC. The flexural strength test was determined of casting and testing the beam of size 500 mm x 100 mm x 100 mm for both the concrete. Similarly, the impact test was done by casting the disc of size 150 mm x 63.5 mm and the test was conducted according to ACI committee 544.1R-82. The split tensile, flexural and impact tests are conducted for the optimized percentage of SF. The compressive and flexural strength tests are conducted by confirming to IS 516-1959[22], and split tensile strength test was done according to IS 5816:1999.²³

RESULTS AND DISCUSSION

Compressive Strength

Both CC and CSC specimens are cast by replacing cement with SF at 0, 5, 10, 15, 20 & 25% and the testing was done with curing days of 3, 7, 28, 56, 90, 180 and 360 days respectively. Figure-1(a) shows the average compressive strength value of CC from 3 to 365 days and 1(b) shows the same for 3 to 50 days. Similarly, 2(a) and 2(b) represents the average compressive strength of coconut shell concrete. The Figure-1(a), 1(b) & 2(a), 2(b) are united under Fig.-1 and 2.

Fig.-1: Compressive Strength of CC

The compressive strength of both the concrete on replacement with SF was compared with 100% cement. The results were found to be increasing from 5 to 10% in both the concrete in comparing with 100% cement for first 28 days, and later on, there is a very mild variation in result from 56 to 365 days. The increase in the percentage of SF level from 5 to 10%, found an increase in compressive strength, and further increase from 15 to 25%, decreases the compressive strength value in both CC (SC2 & SC3) and CSC (SCS 8 & SCS 9) in comparison with SC1 and SCS7. The 28th day compressive strength of CSC at 5, 10, 15, 20 and 25% replacement of cement with SF is 26.8, 27.6, 24.7, 23.4 and 21.4 N/mm^2 , and for CC is 31.5, 32.4, 30.6, 29.6 and 28.4 N/mm^2 , hence the replacement of SF at 10% has the highest compressive strength in both the concrete while comparing with the other percentage level, and this concludes the optimum replacement of cement with SF is at 10%.

Ultrasonic Pulse Velocity (UPV)

The strength and standards of concrete are assessed by an in-situ, non-destructive UPV test. The test is done by transmitting ultrasonic waves through concrete and measuring the time taken between transmission and collection of waves through the structures. Higher the velocity of waves within structure a good quality material can be obtained. The standards of concrete such as the fractures, internal cracks,

strength, porosity, air entrapped can be inferred from conducting this test. The test is done so as to evaluate the potency of the crack outfit. Ultrasonic testing is conducted according to IS 13311-1992^[24]. The test is conducted for both CC and CSC specimens for the 10% replaced cement with SF. The pulse velocity for CC was found to be 5.264, 5.522 and 5.792 m/sec for 3, 7 and 28th-day curing period, which states the concrete are excellent in quality. The pulse velocity for CSC was found as 4.122, 4.273 and 4.444 m/sec for the curing period of 3, 7 and 28, which stated the quality is good. The UPV value was more or less in the same range up to 365 days of curing for both the concrete and it proved to be excellent quality for CC and good quality for CSC. The grading of concrete quality with respect to velocity is given in Table-4.

Fig.-2 Compressive Strength of CSC

Table-4: Velocity Criteria for Grading of Concrete Quality

Pulse Velocity [m/sec]	Grading of Concrete Quality
Above 4500	Excellent
3500 to 4500	Good
3000 to 3500	Medium
Below 3000	Doubtful

Flexural Strength

The casting and testing of the beam to find the flexural strength are done with an optimum percentage of SF. Table-5 shows the test results of both the concrete at 28th day.

Table 5 Flexural Strength of CC and CSC at 28th Day

Test	The CC in N/mm ²		CSC in N/mm ²	
	SC1	SC3	SCS7	SCS9
Flexural Strength	4.33	4.6	3.54	4.1
As per IS 456:2000 (0.7√f _{ck})	3.9	3.98	3.59	3.67
Compressive Strength	31.2	32.4	26.4	27.6

Flexural strength of CC with 100% cement has 10% above the theoretic strength. When 10% of cement is replaced with SF the flexural strength increased by 13.47 % against theoretical strength. In CSC the flexural strength with 100% cement is 1.39% lesser than theoretical strength when 10% of cement is replaced with SF the strength increases by 10.48% against theoretical value. It is concluded that replacing 10% of cement with SF in CSC the flexural strength is increases than its controlled concrete by 9.1%. Hence this concrete can be used where the primary requirement of flexural strength is necessary.

Split Tensile Strength

The casting and testing of a cylinder of size 100mm in diameter and 200mm in height are done to find the split tensile strength for optimum percent level of silica fume and 100% cement. The test results are shown in Table-6, for both CC and CSC.

Table-6: Split Tensile Strength of CC and CSC at 28th Day

Test	The CC in N/mm ²		CSC in N/mm ²	
	SC1	SC3	SCS7	SCS9
Split Tensile Strength	3.3	3.51	2.67	2.8
Compressive Strength	31.2	32.4	26.4	27.6

The split tensile strength of SC1 and SC3 are 10.57 % and 10.80 % of compressive strength to its respective concrete. The split tensile strength of SCS7 and SCS9 are 10.11 % and 10.14 % of compressive strength of respective concrete. This shows CS has similar performance that of controlled concrete when replaced with SF at 10%.

Impact Strength

The disc of size 150mm in diameter and 63.5mm in thickness was cast for both CC and CSC. The test was conducted under an impact testing machine for 3, 7 and 28th day. The casting of the specimen was done for the optimum level of SF, says at 10%, and compared with 100% cement for both the concrete. The number of blows was measured until the initial crack was obtained on the specimen, and the counting of blows was further continued till final crack obtained, i.e until the specimen got broken. Table-7 shows the average impact resistance of CC and CSC at 28th day, which is been compared with compressive value.

Table-7: Impact Resistance of CC and CSC at 28th Day

Initial Crack	Mix Proportion	Compressive Strength in N/mm ²	The average number of Blows	
			Initial Crack	Crack at Failure
CC	SC1	31.2	12	20
CC	SC3	32.4	21	30
CSC	SCS7	26.4	21	29
CSC	SCS9	27.6	26	36

The number of blows took to attain the initial and final crack for CC and CSC at 100% cement is 12 to 20 and 21 to 29, from this study the CC having the compressive strength of 31.2N/mm², has less impact resistance comparing to CS concrete at 26.4 N/mm², this is because of the fibre content present in the CS. The study says the replacement of cement with SF has more impact value than at 100% cement.

Inverted Metallurgical Microscopic Analysis (IMM)

The IMM allows for inspection of the grain size of any materials. It is used in the engineering and manufacturing processes to look for metal fatigue, corrosion, fractures, rupture, bond width that resulted from stress, cracks of any materials. The sample of CC and CSC were cut in to size of 10mm x 10mm x 10mm, and placed in the polisher, where the specimens are initially polished with 300 Grid sand paper to obtain initial smooth surface, and later the same is polished with 600 Grid sand paper to get a fine and glassy surface.

Figure-3 shows the sectional image of coconut shell concrete of 100mm x 100mm size. Core cutting machine is used to cut the specimen of 10mm x 10mm size. Figure-4 represents the glassy finish of CSC after been rubbed from 600 grid salt paper. The polished specimen is placed in IMM to study the bond width between coarse aggregate (CA) - cement mortar (CM) – CS.

Fig.-3: Sectional Image of CSC

Fig.-4: Polished Image of CSC

Fig.-5: 3rd Day Measurement of CC

Fig.-6: 7th Day Measurement of CC

Fig.-7: 28th Day Measurement of CC

Fig.-8: 3rd Day Measurement of CSC

Fig.-9: 7th Day Measurement of CSC

Fig.-10: 28th Day Measurement of CSC

The microscopic test was conducted for the age 3, 7 and 28th day of curing. The test was carried at the range of 100 x zoom. From the test results, it shows that the bond width between CA – CM – CS is reducing for the age 3, 7 and 28 respectively. The figure below shows the bond with for the mentioned samples.

The above figures are the sample of CC taken from IMM. In the figure letter CA indicates coarse aggregate, M indicates mortar, CS indicates coconut shell aggregate and BW indicates bond width, between mortar and aggregate. The red line indicates the measurement taken for the entire bond width between aggregate and mortar. The IMM calculates the value automatically and delivers the value in three forms say maximum, minimum and average value. The Fig.-5 indicates the 3rd-day image of CC having the bond layer thickness between CA and M. The red line on the image indicates the entire measurement of bond width between aggregate and CA and M. The maximum and minimum value was found to be 400.18 and 336.29 micro meters. The average value of the same is automatically derived from the IMM by considering the entire surface taken for the measurement, and the average of 3rd-day curing period is 336.29 micro meter. The same principle is followed for measuring 7th and 28th day. The Fig.- 6 and 7 shows the image of 7th and 28th day of curing period, these images visually represents the decrease in the thickness of bond layer with an increase in curing period. By calculating the maximum and minimum value for the above days, the average value is said to be 264.18 and 144.78 micro meters. The decrease in value clearly represents the increase in the bond layer as the age increases. In the same way, the IMM analysis conducted for CSC shows the maximum value of 284.85, 253.58 and 179.1 micro meter for 3rd, 7th and 28th day. The minimum value for the same is 150.19, 118.04 and 82.75. The average value for the coconut shell concrete decreases from 238.34, 197.71 and 123.23 micrometers for 3rd, 7th and 28th day. The Fig.- 8, 9 and 10 represent the IMM image of CS of 3rd, 7th and 28th-day curing period. The Fig.-11 and 12 represent the IMM values for both the concrete.

Fig.-11: IMM Value - CC

Fig.-12: IMM Value - CSC

The above graph clearly shows that the bond between the aggregate and mortar decreases as the age increases.

CONCLUSION

From the study, the compressive strength was conducted for complete one year, in which the strength is increasing from 3rd day to 28th day and there is a mild variation in strength for the remaining curing days. From the results, the CSC, at 10% SF has the maximum strength of an about 4.5% higher to 100% OPC, and thus confirms the optimum replacement of cement with SF is 10%. UPV test shows the quality of both the concretes is good, which confirms the CS concrete can be used for all kind of structural works. As per IS 456:2000^[25] the flexural strength at 10% replacement of cement with SF has 9.1% higher value comparing to 100% cement. Similar kind of performance was observed with split tensile strength in CSC, in both controlled concrete and at 10% replacement with silica SF. The impact resistance of SCS9 is 24.1% higher comparing with SCS7, similarly while comparing with SC3, 20% of impact resistance is higher in SCS9, this is because of fiber present on a coconut shell and SF, which has more silica content. The IMM analysis indicated the bond width layer decreases with increase in the curing period. The

coconut shell has better bonding nature with mortar while comparing to CA, this could be due to the irregular shape of the CS.

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