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Research Article

A STUDY ON STRENGTH CHARACTERISTICS OF MORTAR AND CONCRETE USING SILICA SAND AS FINE AGGREGATE

Aratchelvan A*

Civil Department, Structural Engineering, PRIST University, Puducherry

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ABSTRACT

In this study, the compressive strength properties and sulphate attack of mortar and concrete using silica waste as fine aggregate were evaluated. The mortar and concrete mixtures prepared with different levels of silica sand were used to partially replace sand. The cement content was kept constant for all mixtures. The cement mortar and concrete were prepared with 0% to 100% by weight of silica sand, the corresponding water-to-binder ratio (w/b) of 0.5 was considered for cement mortar and 0.45 was considered for concrete. Cement mortar mixes developed 28 days compressive strength which ranges from 49.77 MPa to 18.77 MPa and sulphate attack values ranges from 47.52 MPa to 28.69 MPa. The results indicate that the properties of the cement mortar made from silica sand as partial replacement of fine aggregate showed only a marginal increase in strength. The feasibility of utilizing the silica sand in the production of concrete and mortar has been demonstrated.

INTRODUCTION

Concrete is a mixture of cement, natural sand and coarse aggregate. Properties of aggregate greatly affect the durability and performance of concrete. The most commonly used fine aggregate in the production of concrete is natural river sand. Fine and coarse aggregate constitutes to about 75% of total volume of concrete. It is therefore, important to obtain right type and good quality aggregate at site. The demand of natural river sand is quite high in the developing countries due to the rapid infrastructural growth.

Shortage of good quality natural river sand is a great concern faced by construction industries. In India natural sand deposits are being depleted and causing serious threat to environment as well as the society. Increasing extraction of natural sand from river beds causes many problems such as losing water retaining sand strata, deepening of the river courses and causing bank slides, loss of vegetation on the bank of rivers, exposing the intake well of water supply schemes, disturbance to the aquatic life and affecting agriculture due to lowering of underground water table. The variable cost of natural sand used as fine aggregate in concrete has increased the cost of construction. In this situation research began for inexpensive and easily available alternative material to natural sand. Some alternative materials have already been used as a part of natural river sand. Fly ash, slag, rice husk ash, metakaolin etc. were used in concrete mixtures as a partial replacement of natural river sand. Sustainable infrastructural growth demands the alternative material that should satisfy technical requirements of fine aggregate and at the same time it should be available abundantly.

Silica sand is a by- product from the production of glass manufacturing industry. Mortar and concrete is widely used as a construction material which consists mainly of cementing material, coarse aggregate, fine aggregate, and required quantity of water, where in the fine aggregate is usually natural river sand. Due to rapid growth in the construction activity, the available sources of natural river sand are getting exhausted. Also, good quality sand may have to be transported from long distance, which adds to the cost of construction. In some cases, natural river sand may not be of good quality. Therefore, it is necessary to replace Natural River sand in mortar and concrete by an alternate material either partially or completely without compromising the quality of mortar and concrete. Waste glass silica sand is one such material which can be used to replace natural river sand as fine aggregate in mortar and concrete.

Corresponding author:* **Aratchelvan A
Civil Department, Structural Engineering, PRIST University, Puducherry

Experimental Details

Materials

Cement

Ordinary Portland cement (Grade 53) Conformed to BIS: 12269-1987 was used in this research. Its physical properties are given in Table 1.

Fine aggregate

Locally available natural river sand passing 4.75 mm is used and silica sand passing 4.75 mm collected from the glass manufacturing factory was partially used as fine aggregate conforming to Indian standard specifications IS: 383-1970. Table 2 gives the physical properties of the fine aggregates.

Table I Physical Properties of OPC 53 Grade Cement

Sl. No	Experimental studies	Result	Recommended as per IS:12269-1987
1	Standard consistency	29%	30%
2	Initial setting time	45min	30min
3	Final setting time	195min	600min
4	Fineness of cement	2.7	3
5	Specific gravity	3	3.15

Table II Physical Properties of Fine Aggregate

Test	Natural sand	Silica sand
	Result	
Specific Gravity	2.69	2.55
Bulk density (kg/m^3)	1603	2589
Water absorption (%)	0.45	0.45

Mixture proportions

The mortar mixtures were produced with the weight ratio of 1:3:0.5 (binder: sand: water). The w/b ratio was maintained at 0.5. The concrete mixtures were produced with the w/c ratio of 0.45. The cementitious material consists of portland cement blended in laboratory with waste glass silica sand. The cement mortar and concrete were made by partially replacing fine aggregate with silica sand from 0% to 100% by weight. The cementitious material consists of Portland cement blended in laboratory with waste glass silica sand. The control of fresh mortar consistency using the flow-table test conforms to the EN 1015-3 is followed. The mixture proportion details of cement mortar and concrete for 0% to 100% replacement of silica sand is given in Table 3 and Table 4 respectively.

Table III Mixture Proportions for Cement Mortar

Replacement of Silica sand (%)	Quantity of cement (kg)	Quantity of natural river sand (kg)	Quantity of silica sand (kg)	Quantity of water (litre)
0	2	6	0	1
10	2	5.4	0.6	1
20	2	4.8	1.2	1
30	2	4.2	1.8	1
40	2	3.6	2.4	1
50	2	3	3	1
60	2	2.4	3.6	1
70	2	1.8	4.2	1
80	2	1.2	4.8	1
90	2	0.6	5.4	1
100	2	0	6	1

Table IV Mixture Proportions for Concrete

Materials	Quantity (Kg/m^3)
Cement	467
Fine aggregate	786
Coarse aggregate	892
Water	210

Mixing and casting

For the arrived mix proportions, required quantities of materials were weighed. Cement and fine aggregate were mixed in dry state. After adding required quantity water, all the materials were mixed together to obtain the homogeneous mix. After through mixing, final castings of mixes were done immediately. After casting, the test specimens were left in the casting room for 24 hours at a temperature of about 20˚C. The mortar specimens were removed from the respective moulds after 24 hours and were put into a water-curing tank until the time of test or as per the requirement of test. The cubes of size 75mm x 75mm x 75mm were casted for the determination of compressive strength of mortar cubes and cubical specimens of size 100mm x 100mm x 100mm were casted for the determination of sulphate attack of mortar cubes. For the test of concrete specimens, cubical moulds of size 150mm x 150mm x 150mm were casted for the determination of compressive strength. For the determination of split tensile strength cylindrical moulds of size 150mm x 300mm were casted and for flexural strength beam size of about 100mm x 100mm x 500mm were casted. The top surface of the specimens was scraped to remove excess material and to achieve smooth finish. The entire test results obtained is the average value of three readings taken.

Testing

Compressive strength

After the required curing period, the compressive strength test on mortar and concrete specimens incorporating silica sand was performed on standard compression testing machine of 3000KN capacity as per IS: 516-1959. The cubical specimen of size 100mm x 100mm x 100mm and 150mm x 150mm x 150mm were casted and tested for the compressive strength of mortar and concrete cubes respectively at the age of 7days, 14days and 28days. Each of compressive strength test data corresponds to the mean value of the compressive strength of mortar and concrete specimens.

Split tensile strength

The split tensile strength test on concrete incorporating silica sand was performed on standard compression testing machine of 3000KN capacity as per IS: 5816-1999. The cylindrical specimen of size 100mm x 200mm were casted and tested for the split tensile strength at the age of 28days. Each of split tensile strength test data corresponds to the mean value of the split tensile strength of three test cylinders.

Flexural strength

The flexural strength test on concrete specimens incorporating silica sand was performed by providing two steel rollers of 38 mm in diameter, on which the specimen is to be supported, and these rollers shall be so mounted that the distance from centre to centre is 40 cm for 10 cm specimens. The load shall be applied through two similar roller mounted at the third points of the supporting span, that is, spaced at 13.3 cm centre to centre as per IS: 516-1959. The beam specimen of size 500mm x 100mm x 100mm were casted and tested for the flexural strength at the age of 28days.

Sulphate attack test

Sulphate attack test was conducted to assess the mortar quality as per ASTM C 1202-97. To measure the sulphate attack of cubical specimens of size 75 mm x 75mm x 75mm four test specimens were immersed in the water containing $MgSo_4$ solution for 28 days and is then checked for its weight, colour, appearance and compressive strength. The sulphate solution is added at the rate of about 5 mg/1000 ml.

RESULTS AND DISCUSSION

Compressive strength

The compressive strength results of cement mortar and concrete for various partial replacement percentage of silica sand to river sand were found at 7, 14 and 28 days. Effect of partial replacement of silica sand with river sand on compressive strength of mortar and concrete specimens were given in Table 5 & 6. The test results reveal that the compressive strength of mortar specimens ranges from a minimum of about 18.77MPa to a maximum of about 49.77MPa at 28 days. And the compressive strength of concrete specimens ranges from a minimum of about 19MPa to a maximum of about 28MPa. The results show that the strength development is related to the partial replacement of silica sand.

The compressive strength of both mortar and concrete specimens at each age are plotted in Figs.1 & 2. The compressive strength continued to increase as the curing age increases. At later ages (28 days) rate of increase in compressive strength was found to be higher due to the pozzolanic reaction which develops strength at later ages.

In general, compressive strength of mortar specimens was increased with increase in partial replacement of silica sand up to 40%. Compressive strength was found to be decreased beyond 40% of silica sand. The above trend was same for all mixtures irrespective of age. The decrease in strength was about 21% to 62% for 50% to 100% replacement of silica sand when compared to reference mortar mixture. Compressive strength of about 62.23MPa was obtained at 40% replacement for mortar specimen. At 100%replacement of silica sand the decrease in strength was about 62% when compared with reference mortar.

The compressive strength of concrete specimens was increased with increase in partial replacement of silica sand up to 60%. Compressive strength was found to be decreased beyond 60% of silica sand. The above trend was same for all mixtures irrespective of age. The decrease in strength was about 4% to 32% for 70% to 100% replacement of silica sand when compared to reference concrete mixture. Maximum compressive strength of about 32MPa was obtained at 60% replacement for concrete specimen. At 100% replacement of silica sand the decrease in strength was about 32% when compared with reference concrete.

Table V Compressive Strength of Cement Mortar Specimens

Replacement of Silica Sand with Natural Sand	Compressive strength at various Age Mpa		
	7 days	14 days	28 days
0	31.22	37.33	49.77
10	33.77	39.11	55.11
20	36.22	44.83	56.00
30	39.44	48.00	58.67
40	42.77	53.33	62.23
50	30.33	30.33	39.56
60	25.33	31.11	32.00
70	22.12	28.44	26.67
80	16.55	24.88	22.22
90	13.78	18.66	20.45
100	10.66	15.11	18.77

Table VI Compressive Strength of Concrete Specimens

Replacement of Silica Sand with Natural Sand	Compressive strength at various Age Mpa		
	7 days	14 days	28 days
0	19.33	20.04	28.00
10	14.22	22.44	25.00
20	14.59	22.88	26.00
30	14.75	24.00	29.00
40	15.03	24.88	30.00
50	16.11	25.11	31.00
60	16.66	28.00	32.00
70	16.44	24.90	27.00
80	16.11	23.11	26.00
90	15.77	22.52	22.00
100	14.59	21.72	19.00

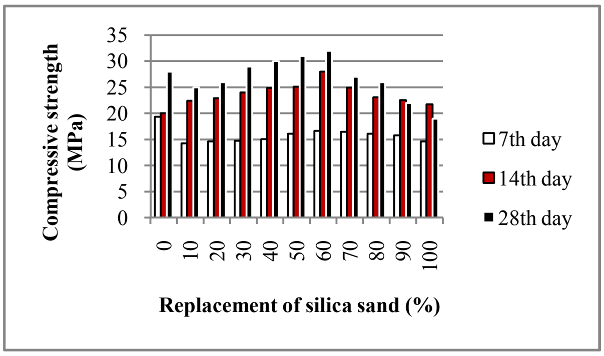

Figure 1 Compressive strength of cement mortar for various replacements of silica sand

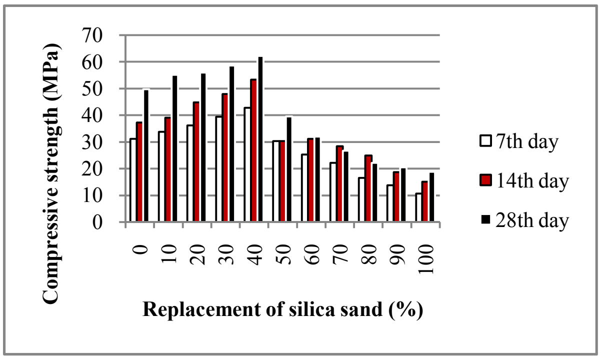

Figure 2 Compressive strength of concrete for various replacements of silica sand

Split Tensile Strength

Split tensile strength is one of the most important fundamental properties of concrete. An accurate prediction of split tensile strength of concrete will help in mitigating cracking problems, improve shear strength prediction and minimize the failure of concrete in tension. The effect of partial replacement of silica sand with natural river sand on split tensile strength of concrete specimens were given in Table 7. Split tensile strength developed for concrete specimens with silica sand percentage varying from 0% to 100% is shown in Figure 3. For reference concrete the split tensile strength value was about 3.17MPa at 28 days. At 10% replacement of fine aggregates with silica sand the strength were observed to be in the range of about 3.36MPa and it was about 3.40MPa at 20% of silica sand when compared to reference concrete. The test results show that the split tensile strength increases up to 60% and it was comparable up to 80% of silica sand when compared with reference concrete.

The test results reveal that the split tensile strength of concrete specimens ranges from a minimum of 2.53MPa to a maximum of 3.74MPa at 28days. According to the test results, split tensile strength values at 28 days are comparable up to 80% of silica sand and decreases by about 5% to 20% for replacement ratios of 90% and 100% of silica sand respectively. Split tensile strength tends to decrease with the increase in percentage of silica sand beyond 80%.

Maximum split tensile strength of about 3.74MPa was obtained for 60% replacement of silica sand. At 100% of silica sand the decrease in strength was about 20% compared to reference concrete.

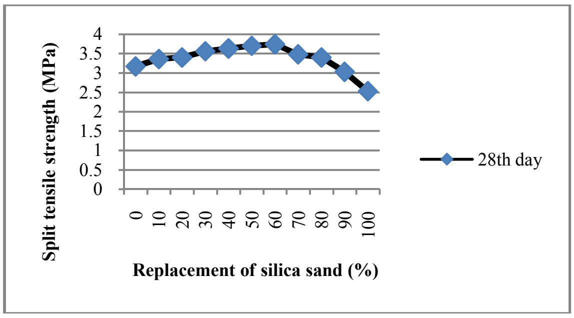

Figure 3 Split tensile strength of concrete for various replacements of silica sand.

Table VII Split Tensile Strength of Concrete Specimens

Replacement of silica sand with natural sand (%)	Split tensile strength at 28 days (MPa)
0	3.17
10	3.36
20	3.40
30	3.56
40	3.63
50	3.70
60	3.74
70	3.48
80	3.40
90	3.03
100	2.53

Flexural strength

The flexural strength results of concrete for various partial replacement percentage of silica sand to river sand were found at 28 days. Effects of partial replacement of silica sand with river sand on flexural strength of concrete specimens were given in Table 8. The test results reveal that the flexural strength of reference concrete was about 3.66MPa. The test results show that the flexural strength was comparable up to 90% of BA which is about 3.54MPa.

Variation of flexural strength for partial replacement of sand with silica sand is shown in Figure 4. According to the test results flexural strength at 28 days values are observed to decrease by 15% at 100% of silica sand when compared to reference concrete. The test results show that the flexural strength was comparable up to 90% of silica sand. Whereas, the flexural strength of concrete specimens decreases beyond 90% of silica sand.

Maximum flexural strength of about 4.21MPa is obtained at 60% replacement of silica sand. At 100% replacement of silica sand the strength decreases to about 15% when compared to reference concrete.

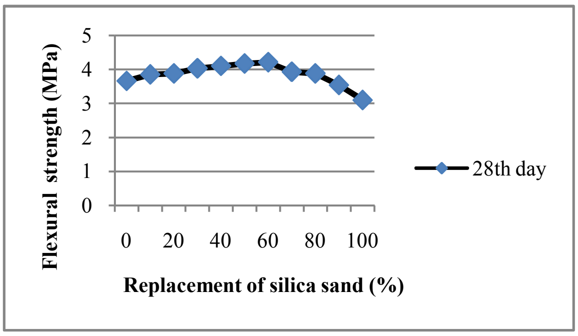

Figure 4 Flexural strength of concrete for various replacements of silica sand.

Table VIII Flexural strength of concrete specimens

Replacement of silica sand with natural sand (%)	Flexural strength at 28 days (MPa)
0	3.66
10	3.85
20	3.88
30	4.03
40	4.10
50	4.17
60	4.21
70	3.93
80	3.88
90	3.54
100	3.10

Sulphate attack

It was found that due to sulphate attack the compressive strength of mortar incorporating silica sand from (0-100%) depends on the percentage of silica sand used. The sulphate attack results of mortar specimens for various partial replacement percentage of silica sand to river sand were found at 28 days. Effect of partial replacement of silica sand with river sand on sulphate attack of mortar specimens were given in Table 9. The test results reveal that the sulphate attack of reference concrete was about 49.77MPa. The test results show that the sulphate attack values decreases beyond 30% of silica sand. This is the most common type and typically occurs where water containing dissolved sulfate penetrates the concrete.

Variation of compressive strength before and after sulphate attack is shown in Figure 5. According to the test results sulphate attack at 28 days values are observed to decrease by 12% to 34% from 40% to 100% of silica sand respectively when compared to reference mortar. Composition and microstructure of the concrete changes may vary in type or severity but commonly include: Extensive cracking, Expansion and Loss of bond between the cement paste and aggregate.

Maximum compressive strength after sulphate attack of about 55.11MPa is obtained at 10% replacement of silica sand. At 100% replacement of silica sand the strength decreases to about 35% when compared to reference mortar. The above effects are typical in attack by solutions of sodium sulfate or potassium sulfate. Solutions containing magnesium sulfate are generally more aggressive, for the same concentration. This is because magnesium takes part in the reactions, replacing calcium in the solid phases with the formation of brucite (magnesium hydroxide) and magnesium silicate hydrates. The displaced calcium precipitates mainly as gypsum.

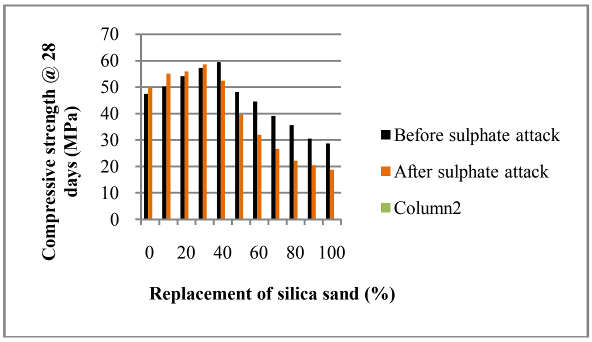

Figure 5 Compressive strength of cement mortar specimens before and after sulphate attack at 28 days of curing.

Table IX Compressive Strength Values of Cement Mortar Specimens Before and After Sulphate Attack

Replacement of silica sand with natural sand (%)	Compressive strength at 28 days (MPa)	
	Before sulphate attack	After sulphate Attack
0	47.52	49.77
10	50.22	55.11
20	54.11	56
30	57.31	58.67
40	59.42	52.45
50	48.20	39.56
60	44.51	32
70	39.09	26.67
80	35.61	22.22
90	30.52	20.45
100	28.69	18.77

CONCLUSIONS

In the present study, cement mortar and concrete was produced by incorporating silica sand as partial replacement for fine aggregate, where silica sand was obtained from waste glass manufacturing industry. The effect of silica sand on cement mortar and concrete is being studied, and the following conclusions are drawn based on the test results obtained:

1. Compressive strength of mortar increases with increase in percentage of silica up to 40%. Beyond 40% replacement level of silica sand, compressive strength was decreased. Maximum compressive strength of about 62.23MPa is achieved at 40% of silica sand.
2. Compressive strength of concrete was marginally increased up to 60% of silica sand. Beyond 60% replacement level of silica sand, compressive strength was decreased. Maximum compressive strength of about 32MPa is achieved at 60% of silica sand.
3. Spit tensile strength and flexural strength of concrete was marginally increased up to 60% of silica sand when compared to reference concrete mix.
4. Compressive strength value after sulphate attack was comparable up to 30% replacement level of silica sand.
5. Replacement of silica sand up to 40% and 60% by weight is recommended for the study of mortar and concrete specimens respectively for economy and comparable strength properties.

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