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STUDY ON CONCRETE USING STEEL SLAG AS COARSE AGGREGATE REPLACEMENT AND ECOSAND AS FINE AGGREGATE REPLACEMENT

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ABSTRACT
Concrete is the third largest material consumed by human beings after food and water as per WHO. Concrete plays a vital role in the design and construction of the nation's infrastructure. Almost three quarters of the volume of concrete is composed of aggregates. These are obtained from natural rocks and river beds, thus degrading them slowly. This issue of environmental degradation, and need for aggregates demands for the usage of any other alternative source. Thus the concept of replacement of coarse aggregate with steel slag and fine aggregate with ecosand seems to be promising. In this study an attempt is made to use steel slag, a by-product from steel industry as replacement for coarse aggregate in concrete and eco sand which is a commercial by-product of cement manufacturing process introduced by ACC Cements as fine aggregate replacement. Initial optimization of materials was done with 7 days strength. M30 grade of concrete was used. Possible optimum replacement of slag material was found to be 60% and possible optimum replacement for ecosand was found to be 40%.Tests on compressive strength, flexural strength, split tensile strength at 7 days and 28 days, and water absorption at 28 days were conducted on specimens. It was concluded that replacing some percentage of coarse aggregate with steel slag enhances the strength. The results showed that replacing about 60 percent of steel slag aggregates for coarse aggregate and 40 percent of ecosand for fine aggregate will not have any adverse effect on the strength of the concrete.

1. Introduction

Steel slag is an industrial byproduct obtained from the steel manufacturing industry. It is a non metallic ceramic material formed from the reaction of flux such as calcium oxide with the inorganic non-metallic components present in the steel scrap. The use of steel slag reduces the need of natural rock as constructional material, hence preserving our natural rock resources, maximum utilization and recycling of by-products and recovered waste materials for economic and environmental reasons has led to rapid development of slag utilization.

Eco sand are very fine particles, a by-product from cement manufacturing semi-wet process, a product by ACC cements (the detailed manufacturing process is withheld by the company for official reasons). It is finely powdered crystalline silica which can replace up to 50% of conventional sand usage in concrete and mortars. Its micro-filling effect reduces pores in concretes and provides better moisture resistivity and thus durability.

In this study, it is proposed to utilize steel slag and ecosand as full replacement of coarse aggregate and fine aggregate respectively in the production of concrete. Tests for compressive strength, flexural strength, split tensile strength and water absorption were conducted on the concrete blocks. Durability test was also conducted on the specimens. Cost analysis for M40 (steel slag and eco sand) were compared.

2. Materials Used

The materials used are normal fine aggregate, normal coarse aggregate, steel slag, eco sand, and OPC of 53 grades after tested for their properties according tocodal provisions IS 2386:1963and the results are given in tables.

Steel slag: The steel slag used here is an air cooled slag and is collected from Dennis steel plant at Arakonam of Tiruvallur district. Its properties were given in Table 1 and Table 3.

Fig.1 Sample of Steel Slag

Ecosand: Ecosand is a byproduct obtained from the process of manufacture of cement, through semi-wet process. It is introduced by ACC Cements, Madukarai, Coimbatore. The main constituent of the ecosand is crystalline silica. It is crystalline white in color. Ecosand has been tested safe against limits of deleterious materials and soluble silica for alkali aggregate reactivity as per IS383. Its properties were given in Table 1 and Table 2.

Fig.2 Sample of Ecosand

Water: Water is needed for the purpose of hydration of cement and to provide workability during mixing and placing of concrete. For this study portable water with pH value 7 and conforming to the specifications of IS456-2000 is used for concreting as well as curing of the specimens.

Table 1: Physical Properties of Steel Slag and Ecosand

Property	Steel slag	Ecosand
Specific gravity	2.61	2.35
Loose density	1382kg/m^3	1460kg/m^3
Compacted Density	1520kg/m^3	1610kg/m^3
Fineness modulus	-	3.1
Grading zone	-	IV
Crushing strength	26%	-
Impact strength	12.86%	-

Table 2: Chemical Composition of Ecosand

Constituent	Composition (%)
Silica (SiO_2)	58-60
Alumina (Al_2O_3)	2-3
Iron	1-3
Magnesium oxide(MgO)	0.4-1
Calcium oxide (CaO)	20-25

Table 3: Chemical Composition of Steel Slag

Constituent	Composition (%)
Aluminum oxide	1-3
Calcium oxide	40-52
Chromium oxide	-
Iron oxide	10-14
Magnesium oxide	5-10
Manganese oxide	5-8
Phosphorus oxide	0.5-1
Potassium oxide	-
Silica	30-35
Sodium oxide	-
Titanium oxide	-
Water Absorption	0- 3

3. Optimization

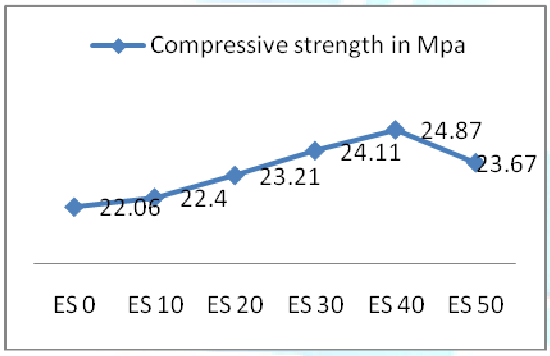
3.1 Optimization of Ecosand:

Optimum replacement of ecosand has been found by considering 7 days strength of mortar cubes of size 7.06x 7.06 x 7.06 cm. Mortar cubes were cast taking 1 part of cement and 3 parts of sand with 0%, 10%, 20%, 30%, 40%, 50% of replacement with ecosand. Three cubes for each replacement were cast. It was found that the optimum level of replacement of ecosandwas 40%.

The following Table 4 and Fig.3 shows the 7 days strength of the mortar cubes cast.

Table 4: 7 days Compressive strength

S.No	% Replacement of Ecosand	7 days Compressive Strength (Mpa)
1	0	22.06
2	10	22.40
3	20	23.21
4	30	24.11
5	40	24.87
6	50	23.67



Note: ES-Ecosand

Fig.3: 7 days Compressive Strength

3.2 Optimization of Steel Slag: Based on the mix design, the mix proportions for M40 grade concrete, using steel slag as coarse aggregate replacement material are shown in Table 5

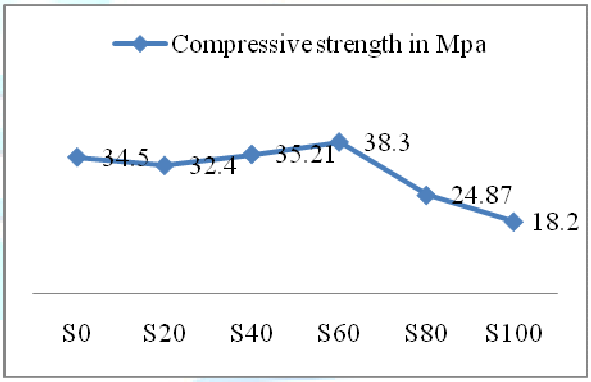
Table 5: Mix proportions for Slag replacement

S.No	Replacement of Steel Slag in %	Mix Proportion
1	0	0.45:1:1.22:2.4
2	20	0.45:1:1.22:2.39
3	40	0.45:1:1.22:2.37
4	60	0.45:1:1.22:2.35
5	80	0.45:1:1.22:2.34
6	100	0.45:1:1.22:2.32

Cube moulds of size 100x100x100 mm were used. They were cleaned thoroughly using a waste cloth and then properly oiled along its faces. The amount of coarse aggregates, fine aggregates were measured based on their weight and then they were mixed manually on a water tight platform under standard conditions. Water was added gradually until all the materials had been adequately mixed together to form a uniform mix. Concrete was then filled in mould and compacted using a standard tamping rod. 3 cubes for each replacement were cast. It was found that the optimum level of replacement of ecosand as 60%. The following Table 6 and Fig.4 shows the 7 days strength of the mortar cubes casted.

Table 6: 7 days Compressive Strength

S.No	% Replacement of steel slag	7 days Compressive Strength (Mpa)
1	0	34.5
2	20	32.40
3	40	35.21
4	60	38.3
5	80	24.87
6	100	18.2



Note: S-Steel slag

Fig.4: Compressive strength of cubes at 7 days

4. Casting of Test Specimens

Fig.5 shows the specimens for compressive strength test, flexural strength test, split tensile strength and water absorption test were caste considering 60% replacement of steel slag for coarse aggregate and 40% replacement of ecosand for fine aggregate. Cubes of size 10cm x 10cm x 10cm were caste for compressive strength test, cylinders of length 30cm and diameter 15cm were caste for split tensile test and prisms of length 75cm and sides 15cm were caste for flexural strength test. Mix proportion of 0.45:1:1.22:2.4 with 0.45 as water cement ratio, i.e. which has 60% steel slag replacement material and 40% ecosand replacement material is used to caste all the specimens.

Fig.5Casting of specimen

5. Experiments Conducted on Concrete Samples

Mean compressive strength test was carried out for 28 days old cubes of grade M40,replaced with coarse aggregate and fine aggregate by Steel slag and Ecosand of 60% and 40% respectively. For durability tests, other sets of cube samples (size, 150 mm) from Steel slag and Ecosand replaced concrete with replacement of coarse aggregate and fine aggregate by SA and ES of 60% and 40%respectively were prepared, water cured for 28 days and dried for one day.

Rapid Chloride Penetration test (RCPT) was performed as per ASTM C 1202 to determine electrical conductance of CC and 30% rapid indication of its resistance to penetration of chloride ions as a quality control measure. Test method consists of monitoring amount of electrical current passed through 51 mm thick slices of 102 mm nominal diameter of cylindrical specimens for 6 h. For preparation of specimens, coarse aggregates passing through sieve (size, 12.5 mm) were used. RCPT apparatus consists of two reservoirs. Specimen was fixed between two reservoirs using an epoxy bonding agent to make test set up leak proof. One reservoir (connected to positive terminal of DC source) was filled with 0.3 N NaOH solutions and other reservoir (connected to negative terminal of DC source) with 3% NaCl solution. A DC of 60 V was applied and maintained across specimen using two stainless steel electrodes (meshes) and current across specimen was recorded at 30 min interval for duration of 6 h. Total charge passed during this period was calculated in terms of coulombs using trapezoidal rule (ASTM C 1202[17]) as

$$Q = 900 (Io + 2 I_{30} + 2 I_{60} + \ldots\ldots\ldots + 2 I_{330} + I_{360}) .(1)$$

where Q, charge passed (C); I_o, current (A) immediately after voltage is applied; and I_t, current (A) at 't' min after voltage is applied. Standard chloride ion penetrability in specimens based on current passed is given as: high, 4000; moderate, 2000-4000; low, 1000-2000; very low, 100-1000; and negligible, <100.

6. Results and Discussion:

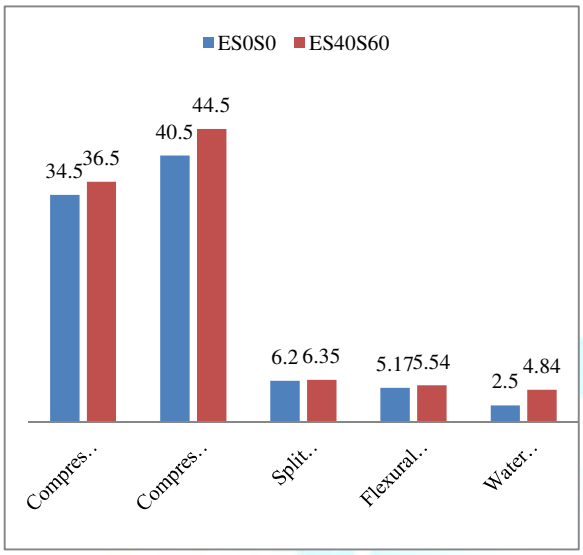
6.1.Concrete:

The 7days and 28 days strength were found for compressive strength test and 28 days strength for other tests. The results are given in the following Table 7. It was found that there was a certain percentage increase in strength in specimens with 40% ecosand as fine aggregate replacement material and 60% steel slag as coarse aggregate replacement material when compared with normal concrete specimens of M40 grade concrete. The results are shown in Fig.6.

Table 7: Various Test Results of Specimens

Test	Specimen results			
	ES0S0		ES40S60	
	7 days	28 days	7 days	28 days
Compressive strength, Mpa	34.5	40.5	36.5	44
Split tensile strength, Mpa	-	6.2	-	6.35
Flexural strength, Mpa	-	5.17	-	5.54
Water absorption	-	2.5	-	4.84
RCPT	Low(1945 Coulombs)		Moderate(3840 Coulombs)	

Note: ES-Ecosand, S-Steel slag



Note: ES-Ecosand, S-Steel slag

Fig.6: Various Test Results of Specimens

6.2.Durability Test

Compressive strength of M40 specimens after conducting durability tests at the age of 90 days immersion was found out . Quantitative difference in weightloss in acid immersion and weight gain in chloride andalkaline immersion has occurred when steel slag and eco sand replacedwith concrete cubes as shown in table8. In acid, compressive strength is not much affected in M40 concrete due to presence of calcium oxide, which imparts strength with age. It is thesteel slag and ecosand, which acts as a filler material and easily combines with basic oxides to form various silicates, there by increasing its impermeability. In NaCl and NaoHsolutions, compressive strength is not much affected compared with conventional cubes.

Table8 Quantitative difference in weight loss/gain of S and ES replaced concrete with conventional concrete

Specimen	Acid test	Chloride test	Alkaline test
	Weight loss %	Weight gain, %	
10% S&ES	0.06	0.02	0.03
20% S&ES	0.08	0.04	0.09
30% S&ES	0.13	0.06	0.10

Table 9—Gain in weight characteristics

Specimen	Weight before	Weight after	Increase in weight	Weight gain%
	RCPT kg	RCPT kg	kg	
Specimen-I (M40)	1.072	1.089	0.017	0.16
Specimen-II (S60&ES40)	1.065	1.079	0.014	0.14

Table 10—Current penetrability characteristics

Period of notice Min	Current penetrability ,C	
	Specimen I (S60&ES40)	Specimen II (M40)
0	0.0619	0.101
30	0.0645	0.105
60	0.0688	0.119
90	0.0712	0.124
120	0.0757	0.139
150	0.0811	0.146
180	0.0858	0.155
210	0.0898	0.166
240	0.0950	0.178
270	0.1110	0.180
300	0.1325	0.181
330	0.1487	0.181
360	0.1522	0.181

6.3.Chloride ions penetrability characteristics:

The weight gain characteristics were shown in Table 10. Weight gain of specimen penetration for normal concrete is more when compared with S60&ES40 due to increase of filler effect (Table9). Current penetrability values in coulombs are given in Table10 .Using Eq(1) for specimen 1 (M40 CC),Q=1945 coulombs and for specimen 2(M40 by S60&ES40 replacement),Q=3840 coulombs, indicating chloride ion penetrability as moderate. It was found that average chloride penetrability for all the replacements is low and moderate thereby quality assessed is acceptable. Overall quality with replacement of steel slag and eco sand is permissible. Decrease in water content combined with the production of additional filler material reduces pore interconnectivity of concrete thereby reducing permeability. Reduced

permeability results in improved long-term durability and resistance to various forms of detoriation

7. Cost Analysis:

The cost analysis plays an important role in deciding the economic design. Aggregates are the

main ingredient of concrete which is costlier and also rarely available. Hence the costlier material scan be replaced, so it is necessary to make cost analysis. Material required and their cost for providing per m^3 concrete for M40 grade is shown in Table 8 .

It was obtained that the cost consumption is decreased in the range of 1.8 % to 39.09 % for the combinations compared to M40.This shows that percentage of aggregate replacement by steel slag and eco sand increases cost saving in the production of concrete.

It was also observed that the combinations ES30S60 and ES40S60 showed 23.9% and 34.09% of cost reduction respectively.

Table 8: Cost Compared with M40 Concrete

S.NO	SPECIMEN	SLUDGE		CEMENT		ECO SCAND		COST SAVED (RS)	COST SAVED (%)
		Kg	Rs	Kg/m^3	Rs	Kg/m^3	Rs		
1	S50	110	--	440	2200	--	--	120	5.17
2	S60	165	--	385	1925	--	--	395	17.03
3	ES30S60	55	--	330	1650	165	115.5	554.5	23.90
4	ES40S60	55	--	275	1375	220	152.0	791	34.09

5. Conclusions

This experimental study has proved to be better method or way in providing strong and durable concrete. It also giving solution to disposal problem of steel slag and eco sand.

It was also found that increase in replacement level of steel slag above 60% decreases the workability of concrete; however this property varies depending upon the source of steel slag .Its optimum replacement was found as 60%.

Ecosand was also found to have characteristics of normal sand and its maximum replacement was found as 40%.When replacement was at minimum level there was good compaction due to smaller size of ecosand and when replacement was increased, it was found that water absorption is Thereby reducing the availability of water for hydration. Thus the optimum percentage was found to be 40%.

When these two optimized values were used together, it was found that it gave good strength comparable to conventional concrete and saves material cost upto 40%.

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