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Study on Replacement of Coarse Aggregate by Steel Slag and Fine Aggregate by Manufacturing Sand in Concrete

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Abstract: Global warming and environmental destruction have become the major issue in recent years. Use of more and more environmental friendly materials in any Industry in general and construction industry in particular, is of paramount importance. Crushed sand as a replaced material to natural sand has become beneficial and is common in the world. This helps in reducing the likely damage to the ecological balance due excessive sand lifting from river beds, affecting the ground water level. Preventing the depletion of natural resources and enhancing the usage of waste materials has become a challenge to the scientist and engineers. The world steel industry produces about 780 Mt of crude steel and an average of about 400 Kg of solid by products is generated in the steel industry per tonne of crude steel. The present investigation deals with usage of steel slag as a partial replacement coarse aggregate and M-Sand to fine aggregate respectively. Initially the optimum percentage steel slag to be replaced is found out by conducting 28 days compressive strength on cubes of size 150 mm x150mmx150mm with 20%, 40%, 60%, 80% replacement of coarse aggregate by steel slag. With these optimum percentage of steel slag the hexagonal shaped paver block specimens of side 125mm and height 80mm were casted and tested for its compressive strength, split tensile strength, flexural Strength and water absorption tests. It is found that replacement of river sand by 25% M sand and coarse aggregate by 40% steel slag gives the maximum strength and is most suitable for areas not exposed to marine conditions.
Key words: Paver block. Steel slag, Manufacturing sand, Natural sand, Natural aggregate, Compressive strength.

Introduction

Conventionally concrete is proper mixture of cement, sand and aggregate. The aggregates occupy the almost 70-75 percent of the total volume of concrete. To meet the global demand of concrete in the future life, it is necessary to use an for alternative material in construction which can fully or partially replaced for the natural aggregate without affecting the property of fresh and harden concrete. Properties of aggregate affect the durability and performance of concrete, so fine aggregate is an essential component of concrete. The most commonly used fine aggregate is natural river sand. River sand, which is one of the constituents used in the production of conventional concrete, has become highly expensive and also scarce. In the backdrop of such a bleak atmosphere there is large demand for alternative materials from industrial waste. Hence an alternative material like utilization of quarry rock dust which can be called as manufactured sand has been accepted as a building material in the industrial construction. Also, steel slag could be used as a partial replacement for coarse aggregate. Good environmental conditions by effective utilization of these by-products will occur which will otherwise remain as a waste material. Steel slag aggregates are already being used as aggregates in asphalt paving road mixes due to their mechanical strength, stiffness, porosity, wear resistance and water absorption capacity. The feasibility of the usage of quarry rock dust and steel slag as substitutes for conventional concrete are investigated. The test results of workability levels and strength are also same when compared to the conventional concrete [1]. The improvement of the concrete mixture properties by addition of steel slag in concrete is observed. The waste material can be replaced by natural aggregates in concrete [2]. The strength of plain concrete and CFSTs with partial replacement of natural aggregates by waste materials in concrete strength is same. The strength by partial replacement of quarry dust as fine aggregate and C& D debris as the coarse aggregate is more than of plain concrete. [3]. The investigation of property of concrete by replacing fine and coarse aggregate by steel slag shows that the strength increased and workability decreased. Also concrete density is decreased [4]. Compressive strength, Split tensile strength, flexural strength are higher when M sand is used as 50% replacement as fine aggregate. [6]. The properties of concrete by replacing natural sand by manufacturing sand is higher. The higher level of fines in manufactured sand increases the workability decrease water content in concrete [7]. The steel slag when used as a replacement for coarse aggregate increases the strength and workability[8].

Materials and Methods

Cement

The Ordinary Portland Cement is generally classified into three grades, they are 33 grade, 43 grade and 53 grade. In this study OPC 53grade has been used. Brand used is Zuari cements OPC 53grade cement and its properties are,

specific gravity	: 3.1
Consistency	: 32%
Initial setting time	: 40min
Final setting time	: 300min

Fine aggregate

Fine aggregate is defined as material that will pass through 4.75mm sieve and will for the most part, be retained on a 75µ sieve. For increased workability and for economy as reflected by use of less cement, the fine aggregate should have a rounded shape. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent and its physical properties are,

Specific gravity of sand	: 2.65
Fines modulus of sand	: 3.45
Sand confirming Zone as per IS 383-1970	: Zone III
Water absorption	: 0.6%

Coarse Aggregate

Coarse aggregate consists of crushed stone with particle size equal to or greater than 4.75mm. It shall comply with the requirements of [9]. In this research coarse aggregate of maximum size 10 mm for paver block and 20mm for cube was used and the specific gravity is 2.71.

Manufacturing sand

The manufactured sand has required gradation of fines, physical properties such as shape, smooth surface textures and consistency which makes it the best sand suitable for construction. These physical properties of sand provides greater strength to the concrete by reducing segregation, bleeding, honeycombing, voids and capillary. Thus required grade of sand for the given purpose helps the concrete to fill voids between coarse aggregates and makes concrete more compact and dense, thus increasing the strength of concrete. Fig 1 shows M sand.

Fig 1 Manufactured Sand

Steel slag

Steel slag is an industrial by-product obtained from the steel manufacturing industry. It is produced in large quantities during the steel-making operations Steel slag can be used in the construction industry as aggregates in concrete by replacing natural aggregates. Fig.2 shows the induction furnace steel slag sample and table.1 shows the properties of steel slag.

Table 1 Chemical composition of steel slag

Elements	Composition
Carbon	1.40%
Oxygen	54.05%
Sodium	0.58%
Aluminium	4.49%
Silicon	18.28%
Potassium	0.33%
Calcium	1.46%
Titanium	0.49%
Chromium	0.32%
Manganese	3.67%
Zinc	0.32%
Iron	14.52%

Fig 2 Steel slag sample

Superplasticiser

Superplasticiser conplast SP430 is used where a high degree of workability and its retention are required, where delays in transportation or placing are likely or when high ambient temperatures cause rapid slump loss. It facilitate production of high quality concrete. Conplast SP430 is primarily highly efficient superplasticiser giving large increase in workability without significant change in compressive strength. Conplast SP430 may be used to produce substantial water reduction resulting in a considerable increase in compressive strength. Fig 3 shows the superplasticiser used.

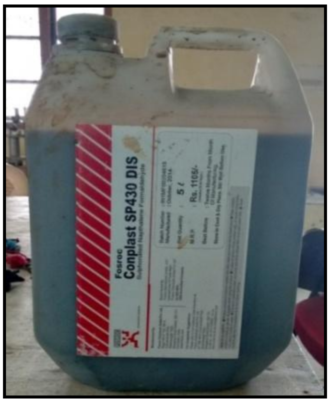


Fig 3 Superplasticiser

Optimization of steel slag

As per [11] concrete grade chosen in present investigation is M_{40} for Medium traffic. Mix design as per [10] for M_{40} graded concrete was performed.

Optimum replacement of Induction furnace steel slag has been found by considering 28 days compressive strength of concrete cubes of size 150 x 150 x 150 mm. Concrete cubes were cast for M_{40} grade by varying coarse aggregate with Induction furnace steel slag by 0%, 20%, 40%, 60%, and 80%. Six cubes for each replacement ratio were cast. It was found that the optimum level of replacement of Induction furnace steel slag was 40%. Table 2 shows the 28 days compressive strength of concrete cubes tested. Fig. 4 shows casting of cubes and its testing.

Fig 4(a) Casting of cubes **Fig 4(b) Compression Testing of cubes**

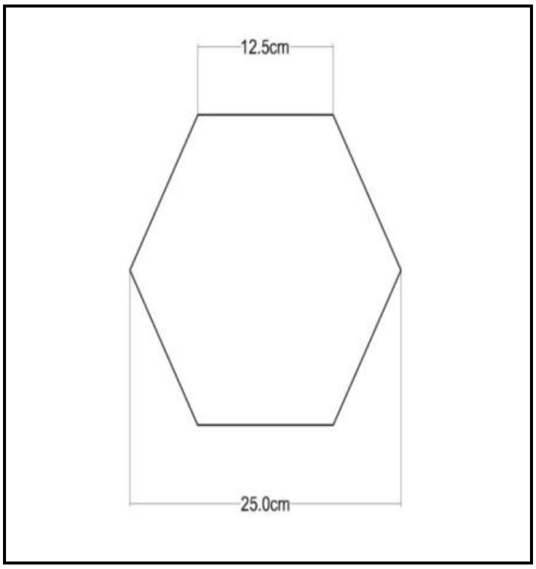
From the table 2, it is observed that there is increase in compressive strength upto 40% and there after decreases. Optimization is found 40% of steel slag replacement.

Table 2 Compressive Strength of concrete cube

% of Slag	28 days Compressive Strength N/mm^2
0%	47
20%	50.2
40%	**59.7**
60%	59.3
80%	56.6

Casting of paver block:

Mix design as per [10] for M_{40} Grade concrete of paver blocks. Fig.5 shows the hexagonal shape Paver block mould of side 125mm, Area $41250mm^2$, and height 80 mm.



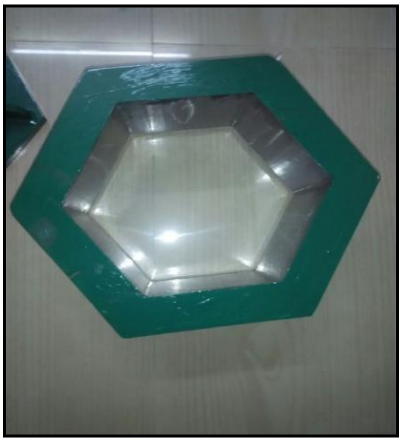


Fig 5 (a)Paver block dimension **Fig 5 (b) Paver block shape**

The paver blocks were casted for a minimum thickness of 80mm for M_{40} Grade [11]. Fig 6 shows the paver blocks casted. The paver blocks were cured for 28 days in curing tank. Tables.3 shows the number of paver block casted.

Table 3 Number of paver block specimens casted

Material Designation	Material Composition	Compressive strength N/mm^2	Split Tensile Strength N/mm^2	Flexural Strength N/mm^2	Percentage of Water Absorption
M1	M0%, S40%	3	2	3	2
M2	M25%, S40%	3	2	3	2
M3	M50%, S40%	3	2	3	2
M4	M75%, S40%	3	2	3	2

M - Manufacturing sand S - Steel slag

Fig 6. casted paver block

Testing of paver block:

As per the [11] the following tests were performed to determine its strength.

Compressive strength test:

All the paver blocks are tested in saturation condition after drying, the surface of the specimen containing no moisture in it. For each mix proportions, three paver blocks are tested at 28 days, using compression testing machine of 2000kN capacity [11]. The tests are carried out at a uniform rate stress level with the specimen properly placed and centered in the testing machine. Loading is applied gradually with the help of hydraulic pumps until the dial gauge reading get reverses its direction of motion. The reversal of needle indicates the total failure of the specimen. The dial gauge reading is noted at the instant of failure, which is ultimate failure load of specimen. The tested specimen is given below in fig.7. The compressive strength is calculated as

Compressive strength = Maximum Load (N) /Plan area (mm^2).

Fig 7 Compressive Strength

Fig 8 Split tensile test

Split tensile strength:

The specimen shall be placed on the testing machine with the packing pieces on the upper face and the bed face, in contact with the bearers. It shall be ensured that the packing pieces and the axes of the bearers are in line with the splitting section .of the specimen. The splitting section shall be chosen according to the following order of priority. The test is carried out along the longest splitting section of the specimen, parallel and symmetrical to the edges, in such a way that the distance of the splitting section to any side face is at least 0.5 times the thickness of the specimen over at least 75 percent of splitting section area. In case the section of the specimen is square, hexagonal or circular in plan, the splitting section shall be chosen in such a way that it is the shortest length passing through the centre of the plan area. Fig 8 shows the split tensile test.

The area of the failure plane(S) of the specimen tested are calculated

S = l x t

where

S = area of failure in mm^2

l = mean of two measurements of the failure length, one at the top and one at the bottom of the specimen, in mm; and

t = mean of three measurements of thickness at the failure plane, one in the middle and one at either end, mm

The split tensile strength of the test specimen is calculated from the equation

T = 0.637 X k X (P/S)

k = 1.12 for 80mm thickness plain paver block as per table 5

where

T = tensile splitting strength in Mpa

P = failure load N

Flexural strength Test:

Fig 9 shows the flexural strength of paver block. The load shall be applied from the top of the specimen in the form of a simple beam loading through a roller of diameter of 25mm placed midway between the supporting rollers. The load shall be applied without shock and increased continuously at a uniform rate of 6 KN/min. The load shall be increased until the specimen fails and the maximum load applied shall be recorded.

The flexural strength of the specimen shall be calculated as follows :

$$F_b = \frac{3Pl}{2bd^2}$$

where

F_b = flexural strength, in N/mm^2
P = maximum load in N
l = distance between central lines of supporting rollers in mm
b = average width of block measured from both faces of the specimen in mm
d = average thickness, measured from both ends of the fracture line in mm

Fig 9 Flexural strength Test

Fig 10 Water Absorption Test

Water Absorption Test:

The test specimen shall be completely immersed in water at room temperature for 24 ± 2 h. The specimen then shall be removed from the water allowed to drain for 1 min by placing them on a 10mm coarser wire -mesh. 'Visible water on the specimens shall be removed with a damp cloth. The specimen shall be immediately weighed and the weight for each specimen noted in N to the nearest 0.01 N (WW*)*. The specimens shall be dried in a ventilated oven at 107 ±7°C for not less than 24 h and until two successive weighing at intervals of 2 h show an increment of loss not greater than 0.2 percent of the previously determined mass of the specimen. The dry weight of each specimen (W_d) shall be recorded in N to the nearest 0.01N. Fig 10 shows the water absorption test conducted.

Percent water Absorption (W percent)

The percent water absorption shall be calculated as follows:

$$W \text{ percent} = \frac{W_w - W_d}{W_d} X\ 100$$

Result and Conclusion

Test results

The results obtained by conducting experiments are presented here.

Compressive strength:

The casted Paver blocks have been tested and the compressive strength test results are listed in the Table 4 and showed in fig 11.

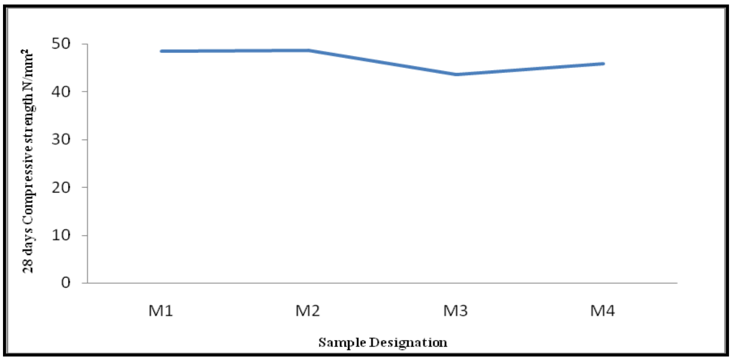


Fig.11 Compressive strength

Table 4 Determination of compressive strength

Mix combination	Specimen Designation	Compressive Strength at 28 days in N/mm^2
M sand 0%, slag 40%	M1	48.48
M sand 25%, slag 40%	**M2**	**48.7**
M sand 50%, slag 40%	M3	43.5
M sand 75%, slag 40%	M4	45.8

It is observed that compressive strength is increased when river sand is replaced by 25% M sand.

Split tensile strength:

The spilt tensile test has been carried out for paver block in shortest length passing through centre area and the results are tabulated in the Table 5

Table 5 Determination of Split Tensile Strength

Mix combination	Specimen Designation	Split tensile strength N/mm^2
M sand 0%, Slag 40%	M1	11.27
M sand 25%, Slag 40%	**M2**	**11.34**
M sand 50%, Slag 40%	M3	8.20
M sand 75%, Slag 40%	M4	9.24

Flexural strength:

The flexural strength test for paver block has been carried out and the results have been tabulated in the Table 6

Table 6 Determination of Flexural strength

Mix combination	Specimen Designation	Flexural strength in N/mm^2
M sand 0%, slag 40%	M1	8.23
M sand 25%, slag 40%	**M2**	**8.35**
M sand 50%,slag 40%	M3	7.37
M sand 75%, slag 40%	M4	7.37

Water absorption test:

The Water absorption test for paver block has been carried out and the results have been tabulated in the Table 7 and Table 8

Table 7 Water absorption

Mix Combination	Sample Designation	Before placing in water (Kg)	After Taking away from water (Kg)	Dry weight (Kg) (after air drying)
M sand 0%, slag 40%	M1	7.613	7.708	7.631
M sand 25%, slag 40%	**M2**	**8.234**	**8.318**	**8.243**
M sand 50%, slag 40%	M3	7.626	7.813	7. 737
M sand 75%, slag 40%	M4	7.624	7.75	7.676

Table 8 Percent of water absorption in Paver Block

Mix combination	Specimen Designation	Percent of water Absorption
M sand 0%, slag 40%	M1	1.01%
M sand 25%, slag 40%	**M2**	**0.91%**
M sand 50%, slag 40%	M3	0.97%
M sand 75%, slag 40%	M4	0.96

Conclusion

- The increase in strength for the replacement of coarse aggregate by steel slag upto 40 percent may be due to shape, size and surface texture of steel slag aggregates, which provide better adhesion between the particles and cement matrix.
- Optimum level of replacement for steel slag is found as 40%. Increase in strength initially is attributed to shape effect and decrease in strength beyond 40% is attributed to porosity of steel slag.
- Optimum level of replacement for M sand is found as 25%. Increase in strength initially is attributed to particle size effect and decrease in strength beyond 25% is attributed to water absorption capacity of M sand.
- The combination 25 percent replacement of M Sand and 40 percent replacement of steel slag gave compressive strength of above 48.7 Mpa. Also split tensile strength flexural strength and water absorbing results showed maximum values for the same percentage.
- From the test results obtained it may be concluded that replacement of river sand by 25% M Sand and coarse aggregate by 40% steel slag is the optimum and most suitable for areas not exposed to marine conditions.

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