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STUDY ON COMPRESSIVE STRENGTH CHARACTERISTICS OF SPHERICAL HOLLOW CORE CEMENT CONCRETE BLOCKS USING FERRO SAND (COPPER SLAG)

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Abstract
A number of industrial waste products in huge quantities are produced each year leading to their accumulation causing environmental problems, disposal and health hazard issues. Some of these products such as fly ash, ground granulated blast furnace slag, ferro sand (copper slag) etc. are used to produce value added products. Ferro sand (copper slag) is produced during smelting and converting steps of pyrometallurgical production of copper. It has been estimated that for every tonne of copper production about 2.2 tonne of copper slag is generated from the world copper production.

The construction industry is facing scarcity of raw materials and hence the use of industrial waste like copper slag can be an alternative in promoting sustainable development for construction industry. Moreover copper slag poses an environmental challenge if not disposed properly.

Similarly disposing the plastic wastes is a very big challenge being faced by all urban local bodies worldwide. If it is buried in the blocks or bricks used for construction, we can extend the recycling period of these hazardous materials to the design life period of the structures, where it is used.

These two waste materials can be used in an effective way as mentioned below:

1. Ferro sand (copper slag) can be used as a partial replacement of fine aggregates used in concrete.
2. The plastic wastes can be recycled and balls can be made. These balls can be buried in the concrete blocks to create spherical voids and thus an arch behaviour can be introduced to have more compressive strength.

The above two concepts were used in this study and the solid and spherical hollow core cubes were made with varying percentages of (0%, 50% and 75%) replacement of ferro sand for natural sand and varying percentage of spherical voids (0%, 5.3%, 11.3%, 15.3% and 23.6%). Cubes of standard sizes were cast and the compressive strengths were compared.

Keywords: Ferro Sand, Concrete, Spherical, Copper Slag, Fine Aggregate.

Introduction

The rapid economic growth of India resulted in a spiralling need for the development of infrastructure facilities like Highways, Airports, Seaports, Industrial Complexes, Technology Parks, Universities, Water supply, Sewage Treatment and Mega Housing Complexes. The ever increasing demand for simultaneous multi-fold construction activities poses a threat not only to the sustainable availability of construction materials but also a threat to the environment management. In Green Buildings internationally effective application of recycled or industrial by products for any element of the construction without affecting the safety and durability is encouraged.

Thus taking into cognizance of impact of development on the environment and considering the concept of Green Construction, an attempt is made to study the Sandwiched use of “Ferro Sand” (Copper Slag), a by-product generated in the Copper Industry and Re-cycled Plastic Balls from Municipal Garbage Plastic Bags for making “Spherical Hallow Core Cement Concrete Blocks” providing different percentage of spherical voids.

In the spherical Hallow Core, the load transfer will be predominantly in the form of direct stresses without inducing any flexural stresses that are inevitable in a beam-column matrix arrangement. Spherical Hallow Core represents a three dimensional arch behaviour.As concrete is very weak in flexure, Load carrying capacity of Spherical Hallow Core blocks will be more than the other geometrical hallow core blocks.

If the behavioural pattern of the Hollow Blocks is changed from the Beam-Column matrix, by introducing the arch action, the compressive strength of the hollow blocks may be increased. This can be achieved by providing Spherical Hollow cores. Hollow cores may be made by placing the plastic balls within the concrete blocks. Plastics balls manufactured by recycling the non-disposable plastic wastes can be used to produce spherical voids.

Another waste and hazardous material which is the by-product of Copper Industry Ferro Sand (Copper Slag) may be used in the concrete as partial replacement of conventional natural sand.Since Copper Slag is heavier than the normally available fine aggregates, the concrete made using them would be heavier. If voids are introduced to reduce the self-weight, the strength also will be reduced. Hence the idea of introducing a proper geometry of voids which will not reduce strength is thought and Spherical Voids are tried to have arch action.

Materials

1. **FERRO SAND (Copper Slag)**

Copper slag (CS) is a glassy granular material with high specific gravity. Particle sizes are of the order of sand and have a potential for use as fine aggregate in concrete. Since the construction industry is a facing a scarcity of source of materials from natural resources such as sand, stone aggregate etc. The utility of industrial wastes will go a long way in promoting sustainable development of construction industry. This slag is currently being used for many purposes ranging from land filling to grit blasting which are not very high value added applications. These applications utilize only about 15% to 22% of the copper slag generated and the remaining materials are being dumped as a waste which requires large areas of land and hence a fast diminishing high value asset. In addition there are apprehensions that the material could also cause environmental pollution. Many researchers have investigated the use of copper slag in the production of cement mortar and concrete as raw materials for clinker. The use of copper slag in cement and concrete provides potential environmental as well as economic benefits. The Ferro sand used has the following characteristics:Specific gravity (SSD): 4.12, Bulk density (SSD): 2.31 gm/cc, Fineness modulus: 3.40

Fig 1: Ferro Sand (Copper Slag) received from M/sSterlite Industries, Tuticorin

2. **PVC Balls**

The Hallow Core is made using P.V.C. Balls available in the market. However, one of the objectives of the concept study is to promote the idea of making PVC Balls out of Municipal Garbage Plastic Bags, such that the recycling period is extended to design life period of the structures, which is generally minimum 30 years.

Four different types of balls having the radii as 3.5 cm, 4.5 cm, 5.0 cm and 5.75 cm were used to create spherical voids of 5.3%, 11.3%, 15.3% and 23.6 % in the cubes. These balls were chosen as available in the market. However balls made up of municipal plastic wastes just making them into a globe shape by wrapping also can be used for this purpose.

Fig 2: PVC Balls

Mix Proportions

Three types of compositions were used for M 7.5 grade concrete as listed below:

Type I: Using only sand as fine aggregate (i.e. no ferro cement is used) along with coarse aggregate, cement and water.

Type II: Using sand and ferro sand in the ratio of 50:50 as fine aggregates along with coarse aggregate, cement and water. (i.e. 50% of replacement of sand by ferro sand).

Type III: Using sand and ferro sand in the ratio of 25:75 as fine aggregates along with coarse aggregate, cement and water. (i.e. 25% of replacement of sand by ferro sand).

Table 1: Details of mix

Sl No	Details of Mix	Fine aggregates	Other Constituent Materials
1	Type I	River sand	Cement, coarse aggregate and water
2	Type II	River sand : Ferro sand = 50 : 50	
3	Type III	River sand : Ferro sand = 25 : 75	

The details of mix proportions for concrete mixes having varying Ferro Sand proportions (50% and 75% of the total fine aggregate material content) which were used for this study are given in Table 2. The basic mix proportions for Type I concrete were used to achieve target compressive strength for concrete mix of grade equivalent to M 7.5. The two other mixes (Type II and Type III) were proportioned by the method of absolute volumes considering the specific gravity of the materials used.

Table 2: Details of Mix proportions for different concrete mixes

Sl No	Concrete Mix Designation	Water / Cement Ratio	Water Content (lit/m^3)	Cement Content (Kg/m^3)	Fine Aggregate (Kg/m^3)		Coarse Aggregate (Kg/m^3)
					Sand Content	Ferro Sand Content	
1	Type I	0.65	132.50	203.85	849.18	0.00	1194.84
2	Type II	0.65	132.50	203.85	424.59	475.54	1194.84
3	Type III	0.65	132.50	203.85	212.29	713.31	1194.84

Experimental Procedure

1. Specimen Preparation

The specimens of 150 mm cubes were cast as per the relevant standards. The specimens were removed from the moulds after 24 hours and cured under water for two different ages wise 7 days and 28 days as per the requirement of test procedures and then tested in saturated surface dry (SSD) condition. For varying spherical voids of 5.3%, 11.3%, 15.3% and 23.6%, the PVC Balls of 35 mm, 45 mm, 55 mm and 57.5 mm radii were used respectively. While keeping the ball within the cubes, care was taken not to punch the PVC ball and the ramming was done perfectly to have the required compaction. The ball was exactly kept at the centre of the cube so that it has equal clearance in all sides i.e. top, bottom and in all four sides.

Fig 2: Placing the Ball

Fig 3: Castingof Cubes

The cubes were de-moulded after 24 hours and immersed in ground level water tanks for 7 days and 28 days according to their testing schedule. The Compressive strength tests were carried out in saturated surface dry conditions according to the prescribed standards.

Fig 4: Curing of Cubes

2. Tests

The following tests were conducted on the prepared concrete specimens for measuring their strength.

1. Compression Test
2. Ultrasonic Pulse Velocity Test

Compression Test

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concretes are employed primarily to resist compressive stresses. Concrete cube specimens of 150mm x 150mm x150mm were cast with different combinations as mentioned earlier. All the cubes were tested for compressive strength on 7^{th} and 28^{th} day after casting.The average value of compressive strength for three specimens in each category is taken as the compressive strength of that category of cube.

Table 3: Details of Test

Sl No		Age of Concrete	Mix Type	% of Spherical Voids in each Type of Concrete	Number of Specimens
01		7 Days	Type I (with 0% Cu Slag)	0.00%, 5.3%, 11.3%, 15.3% & 23.6%	15
02		7 Days	Type II (with 50% Cu Slag)	0.00%, 5.3%, 11.3%, 15.3% & 23.6%	15
03		7 Days	Type III (with 75% Cu Slag)	0.00%, 5.3%, 11.3%, 15.3% & 23.6%	15
04		28 Days	Type I (with 0% Cu Slag)	0.00%, 5.3%, 11.3%, 15.3% & 23.6%	15
05		28 Days	Type I (with 0% Cu Slag)	0.00%, 5.3%, 11.3%, 15.3% & 23.6%	15
06		28 Days	Type I (with 0% Cu Slag)	0.00%, 5.3%, 11.3%, 15.3% & 23.6%	15
Total number of specimens					90

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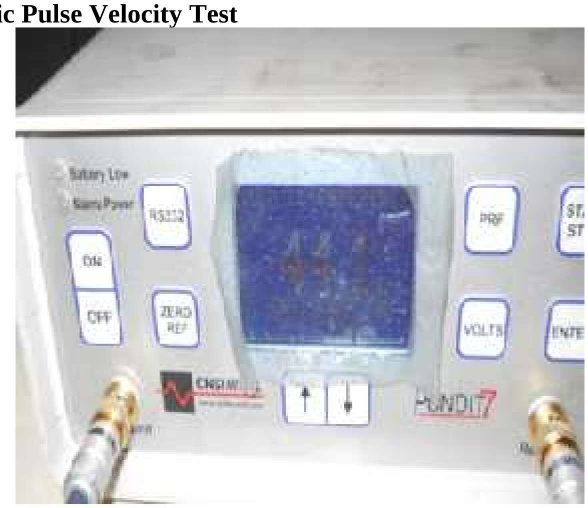
Fig 5: Compression Failure

Fig 6: Ball Position after Failure

Ultrasonic Pulse Velocity Test

The Ultrasonic pulse velocity test essentially consists of measuring travel time, T of ultrasonic pulse of 50 to 54 kHz, produced by an electro-acoustical transducer, held in contact with one surface of the concrete member under test and receiving the same by a similar transducer in contact with the surface at the other end. The value of pulse velocity indicates the quality of concrete. The Ultrasonic pulse velocity depends on the density and elastic properties of the material being tested.The high values of pulse velocity indicate good quality. The values are compared with the table given by Leslie and Cheesman.

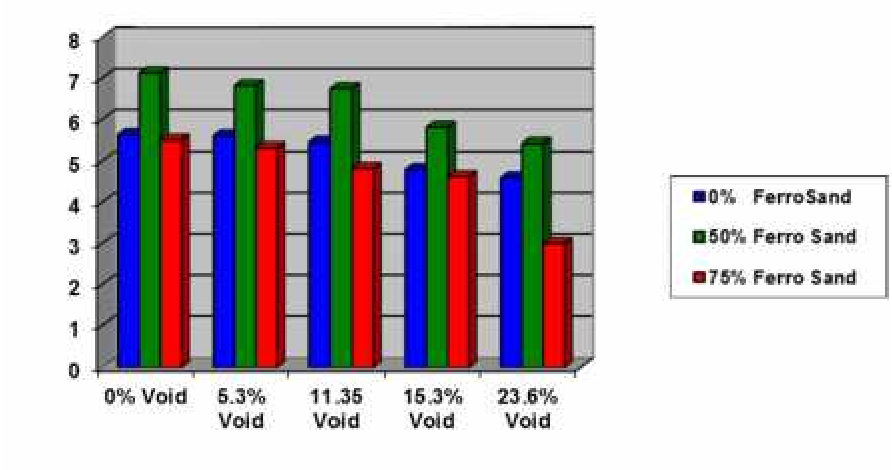
Fig 7 and 8: Ultrasonic Pulse Velocity Test



Results and Discussion

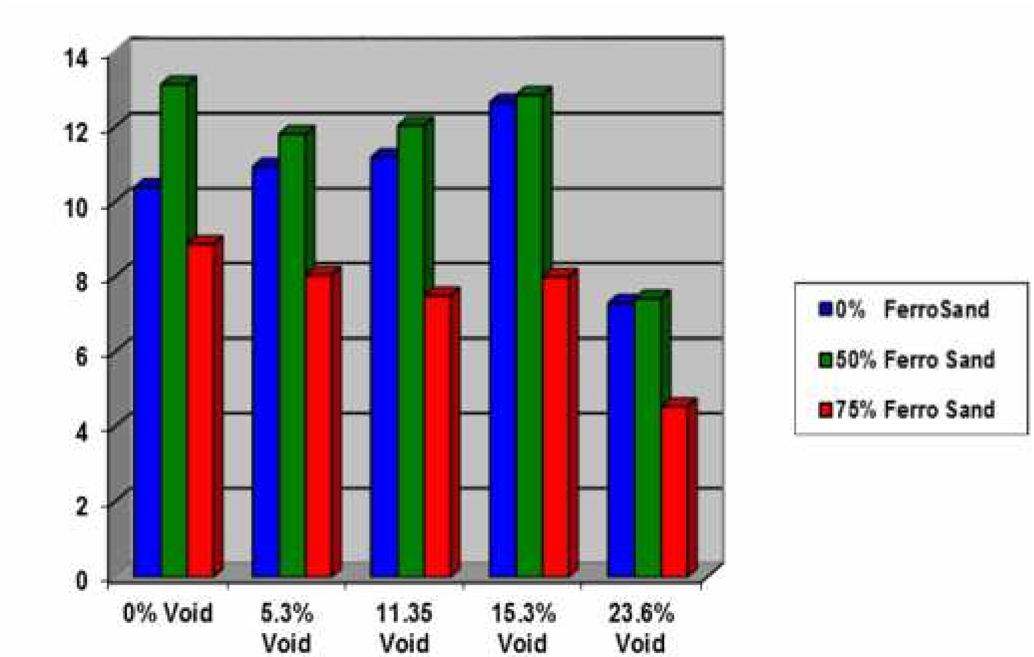
1. **Compression Test**

Chart 1: Chart showing the Compressive Strength of cubes in 7 Days in N/mm^2 with varying % of Ferro Sand and varying % of spherical voids



It is evident from the chart 1 that 50% replacement of ferrochrome slag has shown considerable increase in the 7 days compressive strength irrespective of the percentage of voids. However significant increase is observed with 5.3% of voids and decreases with the increase in the percentage of voids.

Chart 2: Chart showing the Compressive Strength of cubes in 28 Days in N/mm^2 with varying % of Ferro Sand and varying % of spherical voids



Similar observation is found with the 28 days compressive strength also and is presented in chart 2. It is found that 50 % replacement with ferrochrome slag has shown significant increase in compressive strength with 15.3% of spherical voids in concrete. Further increase of spherical voids has resulted in the decrease of compressive strength. Moreover 75% replacement of natural sand with ferrochrome slag has shown considerable reduction in the compressive strength of concrete irrespective of the different percentages of spherical voids.

Chart 3: Chart showing the Compressive Strength of cubes in 7 Days in N/mm² with varying % of Ferro Sand and varying % of spherical voids

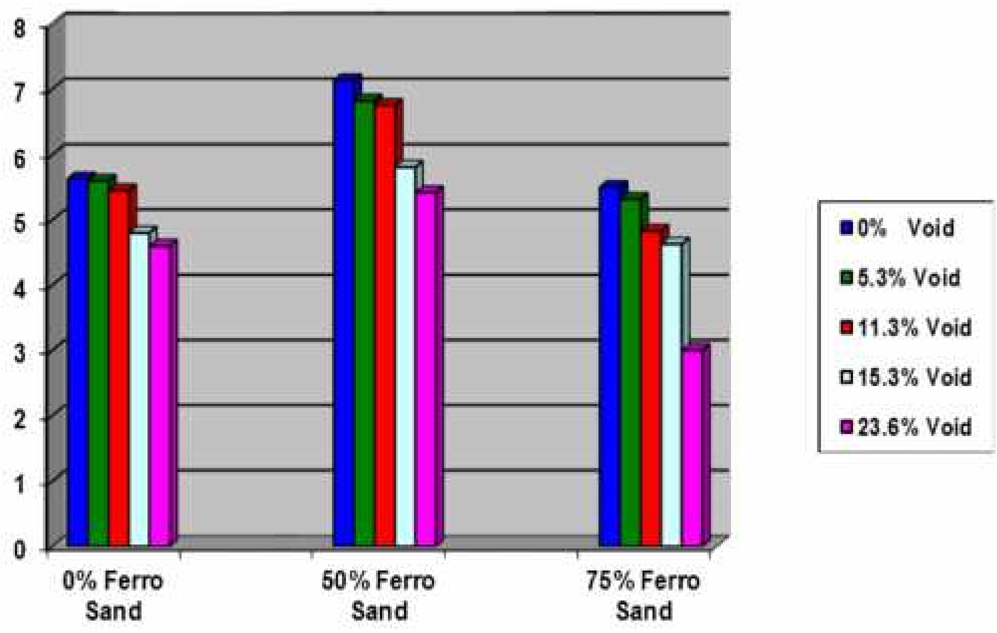
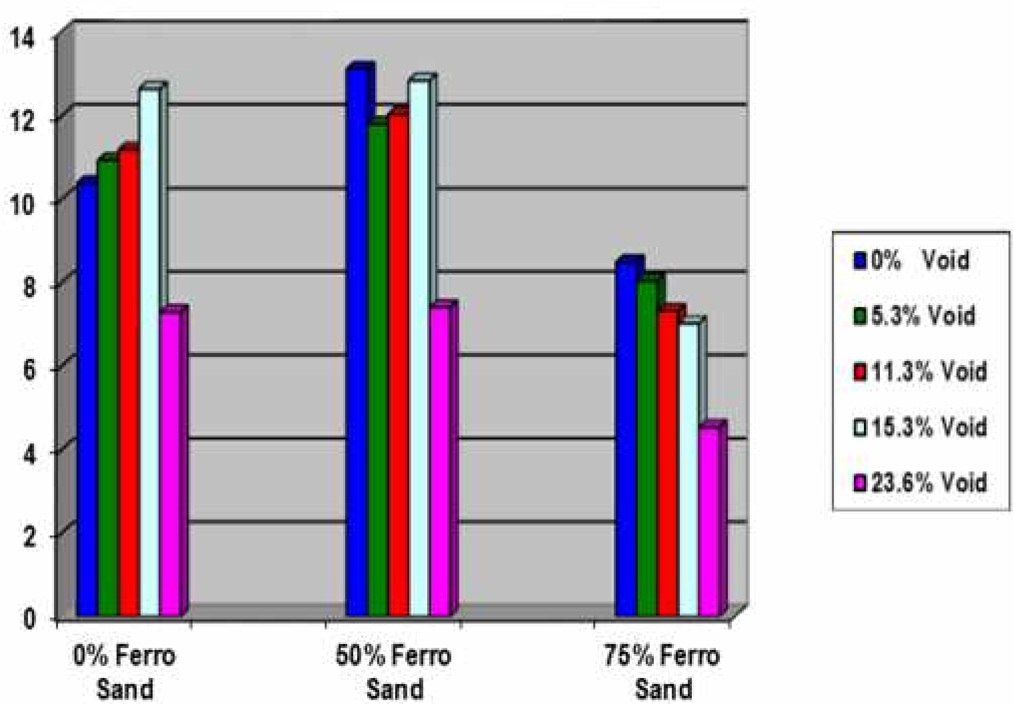


Chart 4: Chart showing the Compressive Strength of cubes in 7 Days in N/mm² with varying % of Ferro Sand and varying % of spherical voids



It can be inferred from chart 3 and chart 4 that 50% replacement of natural sand with ferrochrome slag and spherical voids up to 15.3 % has shown considerable increase in the compressive strength of concrete tested at 7 and 28 days.

2. Ultrasonic Pulse Velocity Test

The Ultrasonic Pulse Velocity Test was conducted on almost all samples and the results were found that the quality of the concrete is good and there was no adverse impact on the usage of ferro sand as the partial replacement of ordinary sand. The results of few random samples are tabulated in table 4 below.

Table 4: Results of Ultrasonic Pulse Velocity Test

Sl.No	Cube Number	**Direct Method Distance (m)**		**Transit Time (Micro Sec.)**		**Pulse Velocity**		**Pulse Velocity (km/s)**	**Concrete Quality as per IS 13311 (Part -1)**
		Top	**Centre**	**Top**	**Centre**	**Top**	**Centre**		
		D (1-1)	**D (1-1)**	**(μs)**	**(μs)**	**(km/s)**	**(Km/s)**		
1	19	0.15	0.15	40.2	42.2	3.73	3.55	3.64	Good
2	19	0.15	0.15	36.2	39.3	4.14	3.82	3.98	Good
3	23	0.15	0.15	36.6	40.6	4.10	3.69	3.90	Good
4	23	0.15	0.15	37.3	41.2	4.02	3.64	3.83	Good
5	21	0.15	0.15	37.2	40.4	4.03	3.71	3.87	Good
6	21	0.15	0.15	36.1	40.7	4.16	3.69	3.92	Good
7	17	0.15	0.15	36.6	39.2	4.10	3.83	3.96	Good
8	17	0.15	0.15	36.2	40.2	4.14	3.73	3.94	Good

Conclusions

1. The Ferro Sand (Copper Slag) may be used as the fine aggregate partially replacing the river sand in cement concrete structures.
2. 50% of replacement of natural sand with Ferro Sand gives more compressive strength to the concrete.
3. Spherical Voids up to 15.3% introduce arch action in the hallow blocks and they have almost same compressive strength as solid blocks.
4. Providing 15.3% of spherical Voids along with 50% replacement of Ferro Sand for the natural sand as fine aggregate give more compressive strength.
5. The non-disposable hazardous wastes like the Ferro Sand (Copper Slag) and municipal plastic wastes can be effectively disposed if they are used as construction materials in the manufacturing of Spherical Hallow Core Ferro Sand Cement Concrete Blocks.
6. The ultrasonic pulse velocity tests conducted on the specimens showed good results on the quality of concrete irrespective of the addition of ferrochrome slag and the percentage of spherical voids in concrete.

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