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Utilization of steel slag in development of sustainable and durable concrete.

Karthik Prabhu T Dr
Coimbatore Institute of Technology, Coimbatore, ntkarthikprabhu@gmail.com

Gowri Shankar M Mr.
Coimbatore Institute of Technology, Coimbatore, mgssalem@gmail.com

Jagadesh P Dr.
Coimbatore Institute of Technology, Coimbatore, jaga.86@gmail.com

Nagarajan V Dr.
Coimbatore Institute of Technology, Coimbatore, citvn2002@yahoo.com

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Utilization of steel slag in development of sustainable and durable concrete.

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Utilization of Steel Slag in Development of Sustainable and Durable Concrete

Karthik Prabhu T
Assistant Professor, Department of Civil Engineering,
Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India
ntkarthikprabhu@gmail.com

Jagadesh P
Assistant Professor, Department of Civil Engineering,
Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India
jaga.86@gmail.com

Gowri Shankar M
Assistant Professor, Department of Civil Engineering,
Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India
mgssalem@gmail.com

Nagarajan V
Professor, Department of Civil Engineering,
Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India
citvn2002@yahoo.com

***Abstract*—This paper reflects the results of an experimental investigation of the strength, permeability, abrasion, carbonation, and shrinkage characteristics of concrete containing various percentages of steel slag as partial replacement of natural fine aggregates. M 30 Grade concrete was designed as per specific national specifications. Steel slag was used to replace natural sand in the range of 0– 50%. It was observed that the steel slag blended concrete with up to 50% substitution exhibited a comparable compressive and flexural strength when compared to the control specimens. From the Dorry's abrasion test, it was noted that the specimens could be implemented in heavy-duty floor tiles and even extended to pavement construction. The shrinkage strains, water permeability, and carbonation of steel slag blended concrete were observed to be increasing with increasing replacement amounts of steel slag in the place of natural fine aggregates. The concrete containing steel slag replacing up to 40% of natural fine aggregates can be recommended for all heavy load involving structural applications, and substitution levels beyond 40% could be recommended for non-structural applications, pavements, etc.**

Keywords - Steel slag; Recycle; Abrasion; Shringage; Carbonation

I. Introduction

Sustainable development is being currently focused in several industries in recent decades. Concrete, one of the most-consumed construction products in world, must be converted into a sustainable product due to firm environmental laws. Inclusion of industrial and agricultural waste materials in concrete makes to be an efficient and effective way for attaining sustainability [1] [2]. Steel slag is the material leftover after the process of manufacturing of steel in the steel industry particularly in the steel thermo mechanically treated bars production. Disposal of steel slag is one of the most-important environmental issues. While significant pressure is placed on steel manufacturing projects in developed countries to conform to strict environmental standards, many projects in developing nations do not take significant steps to prevent or tone down environmental damage. In order to prevent the uncontrolled release of this steel slag into the environment, steel production companies usually have a disposal facility in the form of a solid waste dump yard or earth fill areas. This is a convenient method of storage since steel slags are often in the form of solid material when gets as a residue from the steel industry. These methods of dumping for land filling and storage in the open areas often require more land, and this disposal results in environmental problems.

One ton of steel production causes the production of 130 – 200 kg of slag, entirely based on the composition of the steel and on the method of steel production process. Steel Slag often seemed to be a granulated material containing all sizes namely large clusters, coarse and very fine particles [2]. Serious environmental problems originated from unrestrained sand and gravel taken from rivers thus depleting the natural resources. Fortunately, present scenario has taken measures to use different recycled and supplementary materials as concrete aggregates, as a partial or full replacement in their natural counterparts [3].

Steel slag which is the by-product of steel and iron manufacturing industries, was commonly used in civil engineering from many years ago. Wastes generated in the form of steel slag from the steel industry are in high amounts and the sizes of the steel slag are ranging from large boulders to dust particles. Since these large quantities of steel slag wastes are generated daily, they are considered to be problematic and hazardous for both industries and also the environment. The safe disposal of these steel slags is one of the most challenging tasks with respect to the environmental concern [4]. The Steel slag makes up a portion of 15–20% of total iron and steel production output [5]. The Steel slag are usually stored or dumped in yards creating negative impact on the environment but on the other hand the demand for the aggregate both coarse and fine aggregate in civil engineering industry is increasing exponentially. In order to meet the great demand on aggregates, many natural resources like the mountains and rivers have been exploited drastically leading to pollution and disturbing the environment. Therefore, it is vital for researchers to pave way for an alternative material in the place of natural aggregate for preserving the natural resources [6].

In India the development in the construction sector is seen progressing very rapidly, more concrete usage is abundantly found almost everywhere for the construction activities [7]. The current research aims to evolve the conventional or usual methods and techniques under the present construction requirement and to improve the properties, also reducing the cost and pollution in the process of producing concrete, the concrete production which involves second largest CO_2 emission in the world [8] [9].

The main technique or method to achieve the environment preservation in the construction sector is to develop or enhance a sustainable method to reuse and recycle the construction materials thus involving the reduction of dumping of the waste materials and extraction of the natural resource for construction [10]. Hence the role of the steel slag in which is the supplementary or the waste material obtained as a residue on the production of steel and iron is being included in this study. With additions of steel slag as fine aggregates, the interface structure will be considerably improved [11].

Nearly 60% of steel slag is mostly used for road engineering and construction works in Japan and European countries, and nearly 98% of the steel slag is utilized as aggregates of cement and bituminous pavement in United Kingdom [12]. And more than a decade ago in Germany, test pavements were built using steel slag as a replacement aggregate for unbound and bound bituminous road.

Even though many research works were done for utilizing the waste or the supplementary materials, the problem still persists in large number in the disposal of the waste, creating a huge menace to the government and environmentalists. The steel slag replacement in concrete component increases the resistance to carbonation, permeability and drying shrinkage similar to normal concrete [13].

The most commonly used material in construction is Cement concrete, it consists of 70 to 80 % of aggregates in the concrete mix. The replacement of the aggregates paves the way for a effective and optimized concrete mix. The mechanical properties and volume stability of concrete induced by the inclusion of steel slag and found that 40% replacement of fine aggregate showed consistent compressive strength along with 5% of rubber chips [14].

The improvement of mechanical and durability properties by the replacement of natural aggregates with steel slag up to a percentage of 45% in the cement concrete was experimented for a w/b of 0.35 and 0.5 respectively and found that early compressive strength is low than that of conventional concrete [15]. But for both the w/b ratios the loss of rate of compressive strength of concrete is higher than the corresponding steel slag replacement. It has been observed that the steel slag has a lower early activity than that of cement and the steel slag in the concrete decreases the early hydration of the cement. The ultimate drying shrinkage at 90th day of concrete having steel slag aggregate is nearly same as that of conventional concrete. The durability aspect in chloride ion penetration and the carbonation is also having high resistance in case of steel slag aggregate blended concrete.

II. MATERIALS AND METHODS

A. *Materials*

Materials Used

Raw Materials and Preparation of Test Specimens

- The raw materials used in the test specimens are as follows:
- Ordinary Portland Cement of 53 Grade
- Natural river sand with specific gravity 2.61; water absorption 0.58%, conforming to Zone II and void content 32% [16]
- Crushed stone serving as coarse aggregates (equal proportions of 20 and 10 mm, having average specific gravity of 2.66); and
- Steel slag with various sizes with angular and uneven surface (obtained from Agni Steel, Ingur, Tamil Nadu, India) with specific gravity of 3.30 and water absorption of 0.6% conforming to Zone I bulk density 2.12 g/cm^3 to 2.10 g/cm^3; fineness modulus 3.46; moisture content 0.15%; angle of internal friction of 51,031°; and void content 46%.

TABLE 1 CHEMICAL COMPOSITION OF STEEL SLAG

Sl. No	*Constituent*	*Composition (%)*
1	CaO	44
2	SiO_2	13
3	FeO	27
4	MnO	5
5	MgO	6
6	Al_2O_3	1.5
7	P_2O_5	6.5
8	S	0.08
9	Metallic Fe	4

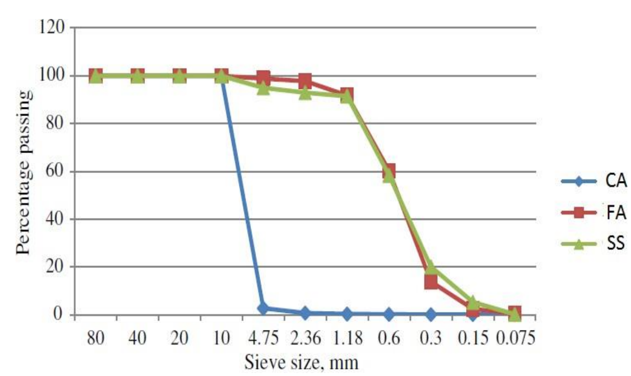


Figure 1. Grain-size distribution of Coarse Aggregates (CA), Fine Aggregate (FA) and Steel Slag (SS) as fine aggregate

Mix Designs

To analyze and study the properties imparted by inclusion of steel slag as fine aggregates on the fresh and also the hardened properties of concrete, a mix design for M30 was chosen (ratio of cement, fine aggregate and coarse aggregate are 1:1.76:2.44 with a water to cement ratio of 0.45). Concrete mixes with different proportions (0–50% fine aggregate (sand) replacement) of steel slags are used. The mixture proportions are given in Table 2. To arrive at desired workability of the concrete Superplasticizer were added. The mixtures were casted at an indoor having temperature range of 25–30°C. In order to determine the workability of the fresh concrete compacting factor test was conducted. Moulds were immediately covered with plastic sheets as soon as casting and de-moulding was done after 24 h. The curing of the specimens were done in water tank at a controlled temperature of 25–27°C. As per Indian Standards (IS), Deutsches Institut fur Normung eV (DIN) [17], and American Society of Testing Materials (ASTM) specifications; tests for determining mechanical and durability properties such as compression test, abrasion test, flexural strength test, carbonation test, water absorption test, water permeability test and shrinkage tests were conducted.

B. Methods

Density

A compacting factor apparatus was used for conducting the Compacting factor test as per as per Bureau of Indian Standards18 for determining the workability of fresh concrete mixtures. The density of fresh concrete mixtures was also measured as per BIS19. The density and workability of concrete with different percentages of steel slag blended concrete were compared with those of the control mix (conventional mix).

Compressive and Flexural tensile strength

Compressive strength was determined by casting Concrete specimens of 100×100 mm and tested for 7, 28, 56, and 90 days of curing and beams specimens were casted of 100×100×500 mm for determining the flexural tensile strength at 7 and 28 days of curing. The specimens were casted with different proportions of steel slag as fine aggregates varying from 0–50% with an increment of 5% for each mix. The specimens were demoulded after 24 h of casting and kept for curing in clean fresh water having the temperature maintained at 27±2°C. The specimens were tested for compressive strength as per IS 516:195920 [18]. Three specimens were tested from each concrete sample and the average value out of the three was taken.

The cube specimen was placed on the compression testing machine in such a way that the load was applied to the opposite side of cubes which were casted and not on the top and bottom sides of the cube. The load was increased gradually at a rate of 140 kg/cm^2/min and care was taken that the load was not applied suddenly; the load was gradually applied until the failure of the specimen. The maximum load applied for the specimen was recorded and the compressive strength was calculated by dividing the maximum failure load and the cross-sectional area of the specimen. Four-point loading beam arrangement was made for the flexural tensile strength, the axis of the specimen was carefully aligned with the axis of the loading device. The rate of the loading was fixed at 180 kg/min. The load was increased until the failure of the specimen and the maximum load of failure was recorded. The flexural strength of the concrete specimens was calculated as the modulus of rupture.

Abrasion Resistance

The measurement of the resistance of the concrete to wear was determined by the abrasion test. The test was done according to IS 1237 [19] on 28th day cured concrete cubes (which were then oven-dried at 60±5°C for 3 days) of 100mm size.

TABLE 2 MIXTURE PROPORTIONS AND PROPERTIES OF FRESH CONCRETE

Mix ID	***Cement***	***FA***	***CA (10mm)***	***CA (20mm)***	***W(kg)***	***SS***	***Ad(M1)***	***CF***	***Densit y (kg/m3)***
SS0	14.67	26.87	21.92	21.92	7.12	0.12	146	0.969	2326
SS5	14.67	25.52	21.92	21.92	7.12	1.64	150	0.973	2335
SS10	14.67	24.17	21.92	21.92	7.12	3.15	153	0.977	2343
SS15	14.67	22.82	21.92	21.92	7.12	4.67	157	0.971	2349
SS20	14.67	21.47	21.92	21.92	7.12	6.18	160	0.964	2354
SS25	14.67	20.15	21.92	21.92	7.12	7.70	164	0.958	2364
SS30	14.67	18.82	21.92	21.92	7.12	9.22	167	0.951	2373
SS35	14.67	17.47	21.92	21.92	7.12	10.72	171	0.938	2372
SS40	14.67	16.12	21.92	21.92	7.12	12.21	175	0.924	2371
SS45	14.67	14.77	21.92	21.92	7.12	13.74	178	0.907	2377
SS50	14.67	13.42	21.92	21.92	7.12	15.27	181	0.889	2383

Weight of the specimens was taken to the nearest 0.500 g. The concrete specimen was fixed on the holding device of the abrasion testing machine such that the surface to be abraded touched the disc, and a load of 600 N was applied on the top of the specimen and the surface area exposed to wear was 100 cm2 (as per the Indian code, for a surface area of 50 cm2 the load applied should be of 300 N. Hence for the surface area of 100cm2 the applied load was given as 600 N). After the completion of 220 revolutions of the abrasion resistance test, the specimen was reweighed and the average loss in thickness, t, was calculated. As per the Indian code, in general-purpose tiles, the average maximum wear should not be exceeded beyond 3.5 mm, and wear on any individual concrete specimen should not be exceed beyond 4 mm. For heavy-duty floors, the value of the abrasion resistance is from 2 and 2.5 mm, respectively.

Water Permeability

Water penetration test was done according to DIN 1048 (1991) [17], on 28th day cured concrete cube specimens of 150mm size. As per DIN 1048, the specimen should be made exposed from above to a constant water pressure of 0.5 MPa acting in normal direction to the mold-filling direction, continuously for a period of 3 days. At the end of the three days, the specimens were taken away from the apparatus and split down at the center to two halves. After 10 min of drying, from the three specimens the maximum depth of penetration was measured, water permeability was calculated as the depth of penetration. If the depth of penetration of water is less than 3 cm, it is under low penetration. If it lies between 3 and 6 cm, it is categorized as medium penetration, and if the depth is above 6 cm, it falls under high penetration [20].

Shrinkage in Concrete

The effect of shrinkage on various concrete mix specimens was studied for 90 days after curing. For conducting these shrinkage tests, three concrete beam specimens of 75×75×300 mm were casted, and after 28 days water curing, using epoxy adhesive two stainless steel demec studs were made bonded at distance 200±1 mm on the surface of the specimens [7]. Mechanical strain gauge having a least count of 0.002mm were used to determine the distance between the deemed points. The first reading on the strain gauge was taken after 6 hours, which was assumed to be the initial shrinkage of concrete. After which the specimens were stored in a control storage unit set to maintain 27±2°C and 50±5% of relative humidity respectively. The gauge lengths of the concrete specimens were measured after every 7 days, starting from the initial measurement, till 3 months [21].

III. RESULTS AND DISCUSSION

A. *Density, Setting and Hardening of Steel Slag Concrete*

The setting property of the concrete was observed by the ease in demolding after 24 h. Workability and density of fresh concrete mixtures are shown in Table 2. The compacting factor of nominal (control) concrete was 0.969. On increment of the amount of steel slag in the concrete mix the compacting factor was observed to have a declining trend. The compaction factor was 0.958 for the concrete mix containing 25% steel slag and it was 0.889 when the steel slag was 50%. This may be because the finer steel slag may require more water and hence decrease the workability.

When the density parameter was measured, a gradual increase in the density was noticed in the steel slag blended concrete compared to the nominal (control) concrete. The density of the nominal (control concrete) was 2,326 kg/m^3 while it was 2,364 kg/m^3 for the concrete containing 25% steel slag, and 2,383 kg/m^3 for the concrete containing 50% steel slag. This gradual increase in the density of concrete on addition of the steel slag can be qualified to the higher specific gravity of the steel slag when compared with the river (natural) sand.

B. *Compressive and Flexural Tensile Strength*

The results for the compressive and flexural tensile strength of steel slag blended concrete are shown in Figs. 2 & 3, respectively. Compressive strength at 7 days of nominal (control) concrete was 26 MPa, while the specimens containing 10% and 20% steel slag as fine aggregates replacement shows a slightly higher compressive strength than the control mix specimens (26 and 27 MPa, respectively) and comparatively good strength of above 26 MPa was observed up to 40% steel slag replacement. The compressive strength at 28 and 56 days specimens with steel slag as fine aggregate replacement up to 40% gave higher results than the control mix. All the other specimens showed the compressive strength ranging from 23 to 30 MPa. The Compressive strength at 90 days of control mix was 35 MPa and the specimens containing 10–40% steel slag gave higher results than those of the control mix specimens. All the remaining specimens exhibited strength above 30 MPa respectively.

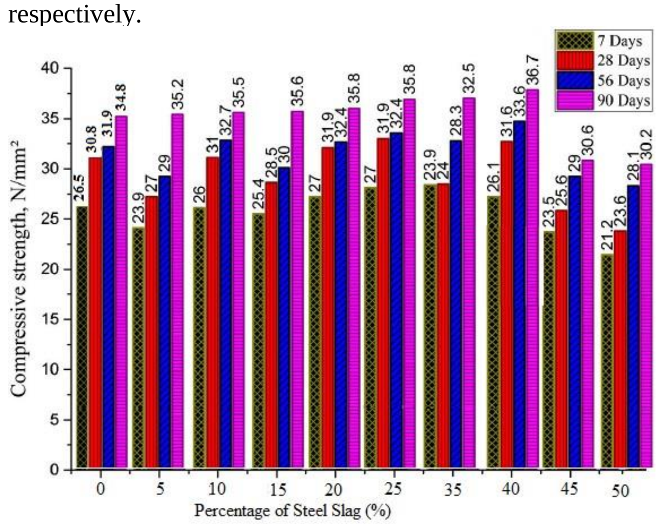


Figure 2 Compressive strength of steel slag blended concrete

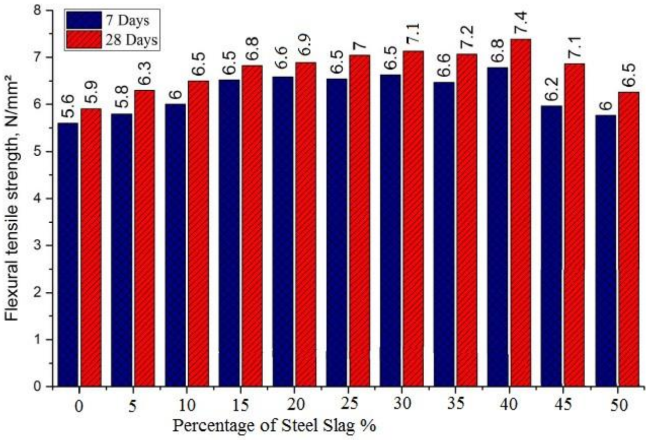


Figure 3 Flexural strength of steel slag blended concrete

The flexural tensile strength at the age of 7 days of the nominal (control) mix exhibited 5.6 MPa. On the increment of steel slag percentage, the flexural tensile strength was found to be increasing up to 40%, and then it was found to decrease slowly. The 28th day flexural strength of the nominal (control) mix was found to be 5.9 MPa and all the remaining mixes containing 5–50% steel slag shows a flexural strength higher than that of the nominal (control) concrete.

C. Abrasion Resistance

The abrasion resistance in requisites of the depth of wear is shown in Fig. 4. According to the Bureau of Indian Standards [19], for general-purpose tiles, the average maximum wear should not be exceeded above 3.5 mm and for the individual specimen the wear should not be exceeded beyond 4 mm. And in the case of heavy-duty floors, the value should lie within 2 and 2.5 mm, respectively.

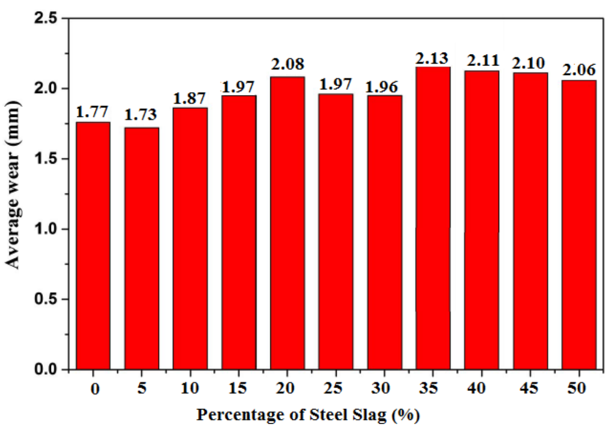


Figure 4 Abrasion Resistance of Steel Slag Blended Concrete

In all the test samples of steel slag blended concrete, the average wear was found increasing [except Steel Slag (SS 5)] as the percentage of steel slag was increasing up to 35 % replacement. Then the wear started reducing till 50% replacement. The depth of wear of the control concrete was 1.77 mm, that of the concrete containing 20% steel slag was 2.08 mm, and that of the concrete containing 35% steel slag was 2.13 mm. All the sample specimens, except those containing 35, 40, and 45% steel slag, could be used in heavy-duty floors. The average wear of SS35, SS40, and SS45 were 2.13, 2.11, and 2.10 mm, respectively, which was slightly greater than the maximum limit of 2 mm for heavy-duty floors. However from Fig 4 it can be seen that all the sample specimens could be used in general-purpose tiles since the average wear was less than the limit stated by the Indian standard code [19] Of 3.5 mm. It was seen that the depth of abrasion followed the compressive strength results. In most of the test specimens, the depth of abrasion was found to be lower when the 28-day compressive strength was higher, and vice versa respectively.

D. Water Permeability

One of the main characteristics that influence the concrete’s durability is its permeability to the access of water and other potentially adverse substances. A suitably low permeability concrete can be obtained by having a sufficient cement content, low w/c ratio, adequate compaction of concrete and proper curing [22].

The permeability tests showing the measurement of the depth of penetration in displayed in Fig. 5. The depth of penetration for control mix was 3.5 cm. It was seen that the depth of water penetration gradually increased with increasing amounts of steel slag in the concrete. This increase can be qualified to the minor difference in the particle size of steel slag when compared with the natural river sand. The water penetration of the specimens containing 30% steel slag was 5.5 cm and that of the specimens containing 50% steel slag was 7.5 cm. The water penetration of the specimens containing 0–35% steel slag can be termed as medium penetration since the range belonging to 3–6 cm, whereas that of the specimen containing 50% steel slag can be termed as high penetration since the limit was above 6 cm. It can be clearly understood that the concrete with steel slag replacement up to 35% has medium water permeability.

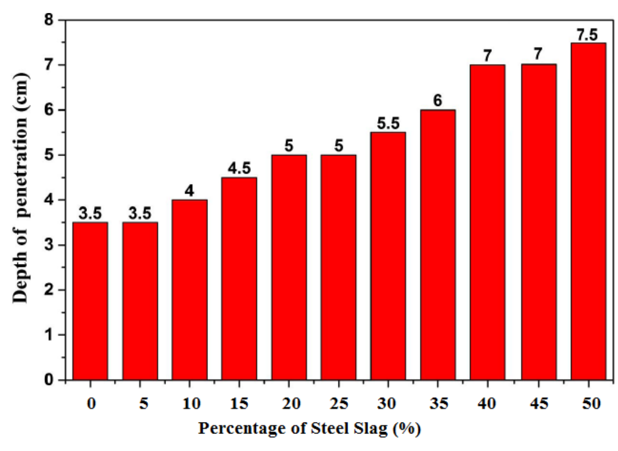


Figure 5 Permeability of Steel Slag Blended Concrete (%)

E. Depth of Carbonation

The depth of carbonation in concrete samples is given in Fig.6 and the specimens showing the depth of carbonation are given in Fig. 7. The depth of carbonation of the control concrete was 15 mm. The carbonation of steel slag concrete was observed to be increasing with increasing

replacement amounts of steel slag. The depth increased to 16 mm in the specimens with 5% steel slag; it was 25 mm for the specimens containing 25% steel slag and 33 mm for the specimens containing 40% steel slag. The depth of carbonation of the specimens containing 40% steel slag is more than double that of the control concrete specimens. The depth of carbonization is found to further increase to 45% and 50% replacement for 34 and 35 mm respectively. The main factors affecting carbonation in concrete are the type and the content of binder, water/binder ratio, degree of hydration, and exposure conditions (concentration of CO2 and relative humidity) [23]. In this study, the increase in carbonation with increasing amounts of steel slag can be attributed to the minor difference in the particle size of steel slag compared to the natural sand.

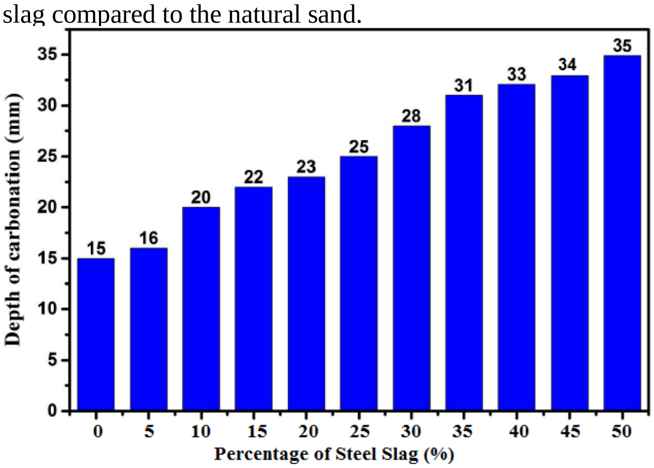


Figure 6 Carbonation of Steel Slag Blended Concrete (%)

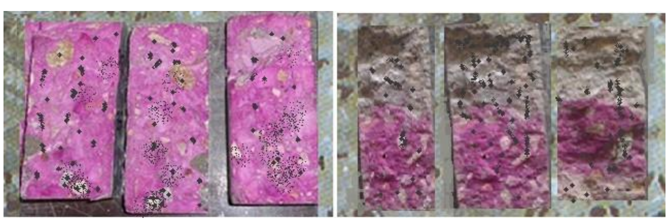
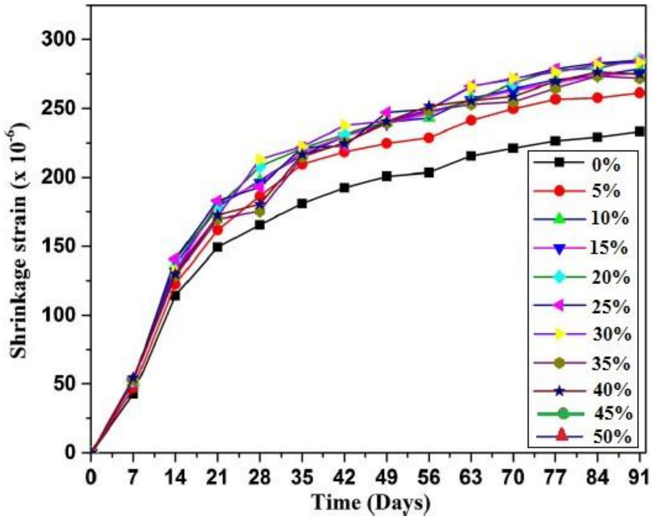


Figure 7 Specimen showing depth of carbonation

F. Shrinkage in Concrete

Fig. 8 reveals the drying shrinkage values of steel slag concrete. The graph showed increasing trend with increased steel slag content. The shrinkage for control concrete at 7th day was found to be 42.82×10^{-6} and the values were found to be gradually increased up to 90 days. The values were found to be 165.66×10^{-6} at 28th day; 203.49×10^{-6} at 56th day, and 233.32×10^{-6} at 90th day. For the specimens containing 30% steel slag, the values were 52.12, 207.68, 247.70, and 285.0×10^{-6} at 7, 28, 56, and 90 days, respectively. When the amount of steel slag were 50%, the values were 55.32, 181.44, 252.66, and 274.75×10^{-6} at 7, 28, 56, and 90 days, respectively. The shrinkage strains of all the steel slag blended concrete specimens (5-50% steel slag) were higher than those of the control concrete specimens, which can be due to the material properties of steel slag.



Figgure 8. Shrinkage of Steel Slag Blended Concrete

IV. CONCLUSION

Experiments were performed to study the suitability of steel slag (obtained from Agni Steels, Engur, Tamil Nadu, India) as a partial replacement for natural fine aggregates (river sand) in cement concrete (from 0 to 50%) on every 5% of increment. The mechanical properties such as carbonation, shrinkage, abrasion resistance and water permeability were studied. The following conclusions were drawn from the study:

- The density of concrete increased with increasing percentages of steel slag in the concrete.
- The reason for the increase can be due to the high specific gravity of steel slag compared with that of the natural (river) sand. The compressive strength of steel slag concrete at 7, 28, 56, and 90 days of curing and flexural tensile strength at 7 and 28 days of curing showed better results when compared with the nominal (control) specimen. The shrinkage strains of the concrete were found to be increasing with increasing amounts of steel slag;
- From the abrasion test, it can be inferred that all the steel slag blended specimens could be implemented in general-purpose and heavy-duty floors. Medium water penetration was observed in the concrete containing steel slag replacement up to 35%, the depth of carbonation of control concrete was 15 mm and that of the concrete containing 50% steel slag was 33 mm. The carbonation of steel slag blended concrete was observed to be increasing with increasing replacement amounts of steel slag; and
- The compressive strength, flexural strength, abrasion resistance, and shrinkage of concrete

containing up to 40% steel slag are comparable with those of the nominal (control) concrete. Medium water penetration was observed in the concrete containing steel slag up to 35%. The depth of carbonation was found to increase with increasing amounts of steel slag in the concrete. Therefore, concrete containing steel slag up to 40% of natural sand could be recommended for all applications and substitution levels beyond 40% could be recommended for non-structural applications, light load carrying pavements, etc.

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