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Properties of concrete manufactured using steel slag

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Abstract

This paper aims to study experimentally, the effect of partial replacement of coarse and fine aggregates by steel slag (SS), on the various strength and durability properties of concrete, by using the mix design of M20 grade. The optimum percentage of replacement of fine and coarse aggregate by steel slag is found. Workability of concrete gradually decreases, as the percentage of replacement increases, which is found using slump test. Compressive strength, tensile strength, flexural strength and durability tests such as acid resistance, using Hcl, H_2SO_4, and Rapid chloride penetration, are experimentally investigated. The results indicate that for conventional concrete, the partial replacement of fine and coarse aggregates by steel slag improves the compressive, tensile and flexural strength. The mass loss in cubes after immersion in acids is found to be very low. Deflection in the RCC beams gradually increases, as the load on the beam increases, for both the replacements. The degree of chloride ion penetrability is assessed based on the limits, given in ASTM C 1202. The viability of usage of SS in concrete is found.

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Keywords: Steel slag; replacement; durability; rapid chloride permeability.

1. Introduction

Aggregate, which makes up 70% of the concrete volume, is one of the main constituent materials in concrete production. Due to the high cost of natural sand used as a fine aggregate and the rising emphasis on sustainable construction, there is a need for the construction industry to search for alternative materials [1]. Steel making slag (SS), one of the most common industrial wastes, is a byproduct of steel production.

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One ton of steel implies the production of 130 – 200 kg of slag, depending on the composition of the steel and on the steel production process. Slag often appears as granulated materials containing large clusters, coarse and very fine particles [2]. Serious environmental problems formerly originated from unrestrained sand and gravel taken from rivers. Fortunately it has been considered for some decades the chance to use different recycled materials as concrete aggregates, even if just in partial replacement of natural counterparts [3]. With the adverse effect of drying, concrete with slag showed a much more refined pore structure than ordinary Portland cement concrete. The changes in pore structure were reflected in strength and shrinkage values [4]. Strength of concrete assumes a greater significance because the strength is related to the structure of hardened cement paste and gives an overall picture of the quality of concrete. The strength of concrete at a given age under given curing conditions is assumed to depend mainly on water cement ratio and degree of compaction [5]. The density of concrete is lower when the natural aggregate is fully replaced by blast furnace slag aggregate. This is beneficial when lower self weight of the final product is needed [8]. In this paper, mix is designed as per the bureau of Indian standards, IS 10262- 1982 for M20 grade concrete with good degree of quality control and mild exposure. For the mix designed, specimens are cast and investigated experimentally. Preliminary attempt is made to study the effect of partial replacement of coarse aggregate and fine aggregate by steel slag in the properties of concrete. The properties involve the compressive strength, tensile strength, flexural strength and durability. The main objective of this paper is to investigate the effect of partial replacement of aggregates by steel slag on the strength and durability properties of concrete and to determine the viability of steel slag usage in reinforced cement concrete (RCC). Use and recycling of steel slag from steel manufacturing industry is an important issue. SS is a byproduct. Not much work has been reported on the use of SS in concrete related to durability. So in this work, SS is used as a partial replacement material for fine aggregate and also for coarse aggregate, while manufacturing concrete, in order to investigate the effect of SS on the strength and durability properties.

2. Experimental Detail

2.1 Material

2.1.1 Cement

Ordinary Portland cement of 53grade is used. It is tested as per Indian standard specification (IS 4031 - 1996). Various properties are given in the Table1. Fineness of cement is determined by means of dry sieving. These test results shows that the property of cement, satisfies the requirements.

Table1. Properties of cement

Properties	Values
Fineness	5%
Consistency	29%
Initial setting time	45 min
Specific gravity	3.15

2.1.2 Aggregates

Steel slag, a by-product obtained from the steel manufacturing plant, is crushed into pieces and used as a fine and coarse aggregate along with conventional fine and coarse aggregate. River sand is used as a conventional fine aggregate and crushed granite as conventional coarse aggregate. Various properties of all the aggregates along with the standards, from Indian codal provisions (IS 383 – 1970) are given in table 2 and 3. The properties of natural fine aggregate and SS are as per the requirements. The crushing and the Attrition values of the steel slag coarse aggregate (SSCA) are higher than that of the standard values. This has to be taken care when these aggregates are to be used in runways, roads and pavements, as moving loads place a vital role than the dead load. The water absorption of SSCA is much higher when compared to that of crushed granite and it also exceeds the standard values prescribed by Indian standard code (IS 2386 - Part III- 1963). SSCAs are cured well before they are used in concrete work. When fully saturated SSCA is used, the absorption capacity of that aggregate is greatly reduced, so that, the water used for hydration of cement is properly utilized and it satisfies the purpose.

Table 2. Properties of Fine aggregate

Properties	River sand	Steel slag	Standard values
Voids in sand	41.17%	56%	---
Specific gravity	2.74	3.0	2.5 – 2.7
Water absorption	1.00%	1.32%	0.1 – 2.0%

Table 3. Properties of Coarse aggregate

Properties	Crushed granite	Steel slag	Standard values
Impact test	9.03%	25.26%	<45%
Crushing test	36.52%	62.03%	<45%
Attrition test	5.40%	4.1%	<2%
Specific gravity	2.80	3.84	2.5 – 2.7
Water absorption	0.5%	5%	0.1 – 2.0%

2.2 Mix Design

As per the recommended procedure of Bureau of Indian standards IS 10262 – 1982, mix ratio is designed with the test results of workability, specific gravity, water absorption and free surface moisture for the materials. Design is stipulated for good degree of quality control and mild exposure. The mix proportions, by weight are 1:1.808: 3.85 (cement: fine aggregate: coarse aggregate) with a water cement ratio of 0.55.

2.3 Specimen details

Using the designed mix, specimens are cast. Size and number of specimens for various tests are given in table 4. RCC beams are cast using mild steel mould of size 100 X 150 mm cross section and 2000 mm long. 10mm diameter mild steel rods are used as top and bottom reinforcement. Stirrups of 8mm diameter bars are used at spacing of 100mm centre to centre (c\c) and for the flexure at 200mm spacing.

Table 4. Size of the specimen

Name of the specimen	Name of the test	Size of the specimen in mm	Number of specimen
Concrete cube	Compression	150 x 150 x 150	51
Prism	Flexure	100 x 100 x 500	2
Cylinder	Split tension	150 x 300	4
RCC beam	Deflection	100 x 150 x 2000	6
Cylinder	Rapid chloride penetration	150 x 50	2
Cube	Acid resistance	150 x 150 x 150	6

2.4 Test Details

In order to consider the effect of partial replacement of steel slag, the proportion of water cement ratio, cement content, method of curing and compaction are kept constant. Cement is not replaced by steel slag because the maximum limit of total addition of performance improver such as fly ash, Granulated slag, Silica fume, Lime stone, rice husk ash, Metakaolin is 5 % during the manufacturing process of ordinary Portland cement as per IS 269-

2013.

The test samples of 1: 1.81: 3.84 concrete mix (Cement: Fine Aggregate: Coarse Aggregate) are produced with crushed granite as coarse aggregate and river sand as fine aggregate. Subsequent test samples are produced with fine and coarse aggregate, progressively replaced by steel slag at 10% intervals, by weight, up to 50%. The water/cement ratio is kept constant at 0.55 throughout the investigation. Three number of 150 x 150 x 150 mm cubes are cast for each mix and cured in water in accordance with IS 10086- 1982.The cubes are crushed at 28 days curing age, to determine their compressive strength. The optimum percentage of replacement is found for each aggregate replacement. Further test procedure is carried out to determine the Mechanical properties such as compression, tension, flexure, deflection of RCC and the durability test such as Rapid chloride penetration test, Acid resistance using Hcl, $H_2SO_4$for that optimum percentage of replacement.

To measure the workability of fresh concrete, slump test is carried out, before casting the specimens, as per IS 1199- 1959. The mould for the slump test measures base diameter of 200 mm, while the smaller opening at the top is 100 mm and 300 mm in height. The slump cone is filled in three layers, tamping each layer 25 times with a 16 mm diameter rod to remove voids. The top surface of the concrete is leveled off. With the cone removed, the height of the slump is then measured.

Among various strengths of concrete, compressive strength has received a large amount of attention, because, the concrete is primarily meant to withstand compressive stress. The procedure is executed as per the IS 516- 1959, using the universal testing machine. The load is applied gradually, till the failure for the specimen. Splitting tests is well known indirect tests used for determining the tensile strength of concrete. The test consists of applying compressive line loads along the opposite generators of a concrete cylinder placed with its axis horizontal between the patterns. Due to the applied line loading a fairly uniform tensile stress is induced over nearly two third of loaded diameter. Due to this tensile stress, the specimen fails finally by splitting along the loaded diameter. The determination of flexural tensile strength is essential to estimate the load at which the concrete members may crack. As it is difficult to determine the tensile strength of concrete by conducting a direct tension test, it is computed by flexure test. The flexural tensile strength at failure or the modulus of rupture is thus determined. The computation of modulus of rupture assumes a linear behaviour of the material up to failure, which is only a rough estimation.

Durability tests are performed as per IS code clause 8.2.2.4 of IS 456 – 2000. Acid resistance test is done by weighing the 28 days cured specimen and the same is immersed in sulphuric acid for 90 days. Weight difference is measured after the curing period. The procedure is repeated for hydrochloric acid for different new specimens.

The rapid chloride penetration test apparatus consists of two reservoirs. The specimen is fixed between two reservoirs using an epoxy bonding agent to make the test set up leak proof. One reservoir (connected to the positive terminal of the DC source) is filled with 0.3 N sodium hydroxide solutions and the other reservoir (connected to the negative terminal of the DC source) with three percent sodium chloride solution. A DC of 60 V is applied across the specimen using two stainless steel electrodes (meshes) and the current across the specimen is recorded at 30 minutes interval for duration of six hours. The total charge passed during this period is calculated in terms of coulombs using the trapezoidal rule as given in the ASTM C 1202.The main objective of the research, was to determine the viability of steel slag in concrete, as fine and coarse aggregate, in a partial optimum percent.

3. Results and discussion

3.1 Optimum percentage of replacement

The compressive strength of concrete cubes at 28 days curing is found as the average of three measurements and is shown in table 5. The compressive strength of concrete increases gradually, as the percentage of replacement increases, up to 40% for fine aggregate and 30 % for coarse aggregate, and then it gradually decreases. Therefore the optimum percentage of replacement for fine aggregate is 40% and for coarse aggregate is

30%. For every addition of gravel, the compressive strength reduced, when compared with the value of the immediate previous level of replacement beyond the optimum level [9].

Table 5. Compressive strength – 28 days

% of replacement	Compressive strength Mpa	
	Fine aggregate replacement	Coarse aggregate replacement
0%	20.67	20.67
10%	19.56	22.80
20 %	20.10	24.75
30%	20.78	28.33
40%	21.67	27.02
50%	19.32	25.06

3.2 Workability

The results of the slump test showed that at 0% replacement level, the concrete mix gave a true slump value of 35 mm. The slump decreases, as the percentage replacement level increases, from 0% to 50% at 10% interval for both the percentage of replacements. It shows that river sand is generally finer than that of steel slag. Water absorbing property of steel slag in both fine and coarse aggregate is higher than that of river sand and crushed granite. Hence for constant water cement ratio of 0.55, more water is absorbed by steel slag leaving behind fewer amounts to mortar, for hydration. The greater the percentage of replacement of aggregates by steel slag, the less the workability of concrete as indicated by slump value in table 6. The results of the slump test shows that all the mixes indicate true slump, irrespective of percentage of replacement [9].

Table 6. Slump

% of replacement	Slump value	
	Fine aggregate replacement	Coarse aggregate replacement
0%	35	35
10%	28	22
20 %	23	17
30%	18	12
40%	13	8
50%	11	3

3.3 Compressive, tensile and flexure.

The various percentages of materials for the optimum percentage of replacement of 30% CA and 40 % FA are shown in table 7. The individual variation of set of 3 cubes is not more than +/- 15% of the average, as per the acceptance criteria of IS 456- 2000.The strength for the different percentage of replacement for conventional concrete and steel slag concrete for both fine and coarse aggregate replacement at 7 days and 28 days are illustrated in Figure 1 and 2.

Table 7. Various percentage of replacement

Concrete with replacement	Cement in %	Fine aggregate in%		Coarse aggregate in %	
		River sand	Steel slag	Crushed Granite	Steel slag
0%	100	100	0	100	0
30 % CA	100	100	0	70	30
40% FA	100	60	40	100	0

From the test results, the compressive strength of concrete increased 4.6% when the coarse aggregate is replaced by 30% steel slag. Likewise, increase in strength of concrete is observed as 27.04%, when the fine aggregate was replaced by 40% steel slag. Compressive strength also increases from 7 days to 28 days by 31%. As the age of concrete increases, the formation of secondary calcium silicate hydrated (CSH) gel will initiate, leading to higher strength.

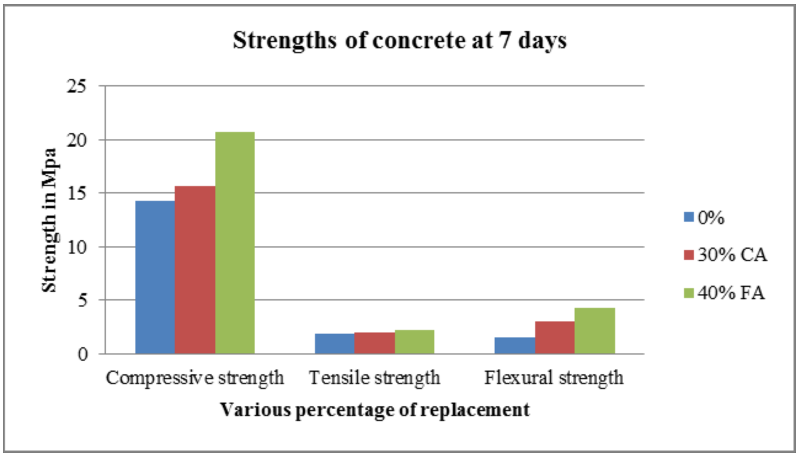

Fig. 1. Strength of concrete at 7 days

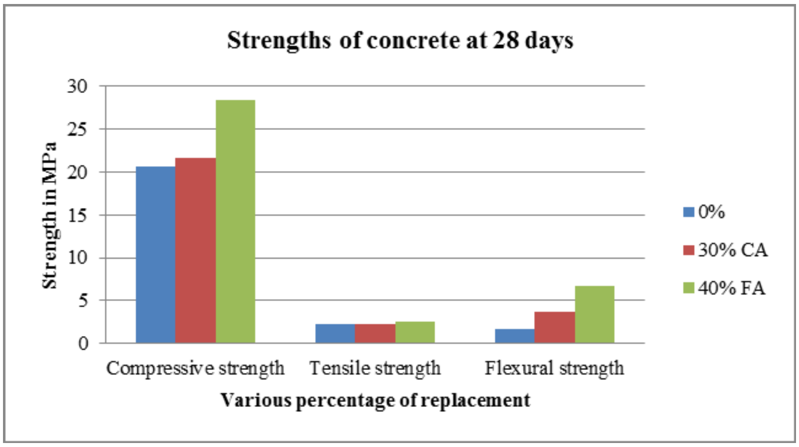

Fig. 2. Strength of concrete at 28 days

When comparing the results with the literature survey [6], by replacing both fine and coarse aggregate together, compressive strength is increased in higher percentage as 23.8%, which is greater than the individual replacement. The flexural strength of concrete decreased 2.1% when both fine and coarse aggregate is replaced by steel slag [6]. While replacing a single factor, the flexural strength increased by 48.1% for 30% coarse aggregate replacement and 74.2% for 40% fine aggregate replacement than the conventional concrete of 0% replacement. The strength estimated by flexure test was higher than the tensile strength of concrete because of the assumption of the linear behaviour of material up to failure.

3.4 Rapid chloride penetration test

The total charge passed during this period is calculated in terms of coulombs using trapezoidal rule as given in the ASTM C 1202. Charges passed in terms of coulombs for various percentage of replacement is shown in Figure 3. IS 456 of 2000 limits the chloride ion penetrability as low when the charges passed falls in between 1000-2000 coulombs and moderate penetrability when it falls in between 2000 - 4000. 30% coarse aggregate replacement comes under moderate penetrability where as conventional concrete and 40% fine aggregate replacement concrete comes under low penetrability. The secondary hydration derived from pozzolanic material such as silica fume, fly ash, steel slag is dependent upon the formation of calcium silicate hydrated gel of the primary cement hydration reaction. It densifies the cement micro structures, producing low permeability concrete [7]. As the age of the concrete increases the permeability characteristics will decrease when pozzolanic materials are added.

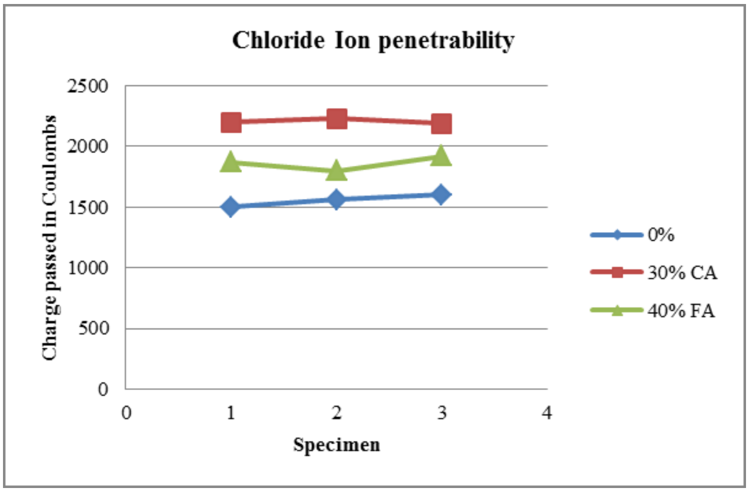

Fig. 3. Chloride ion penetrability

3.5 Durability test

The loss in weight of the cube when immersed in H_2SO_4 and Hcl for all the percentage of replacement is shown in figure 4 and 5. From the test result, the weight loss of 40% replacement fine aggregate by steel slag is lesser when compared to the conventional concrete and 30% coarse aggregate replacement. By adding steel slag, either in fine aggregate or in coarse aggregate, has better acid resistance than our conventional concrete. When compared with the hydrochloric acid, the weight loss is more when immersed in sulphuric acid; this is because the dehydration rate is high in Sulphuric acid than the other. Quantity of CSH gel formed by the hydration process, when immersed in sulphuric acid will be comparatively lower than in Hcl immersion. The outer surface of the cubes immersed in H_2SO_4 has been eroded than the cubes immersed in Hcl, which is shown in figure 6.

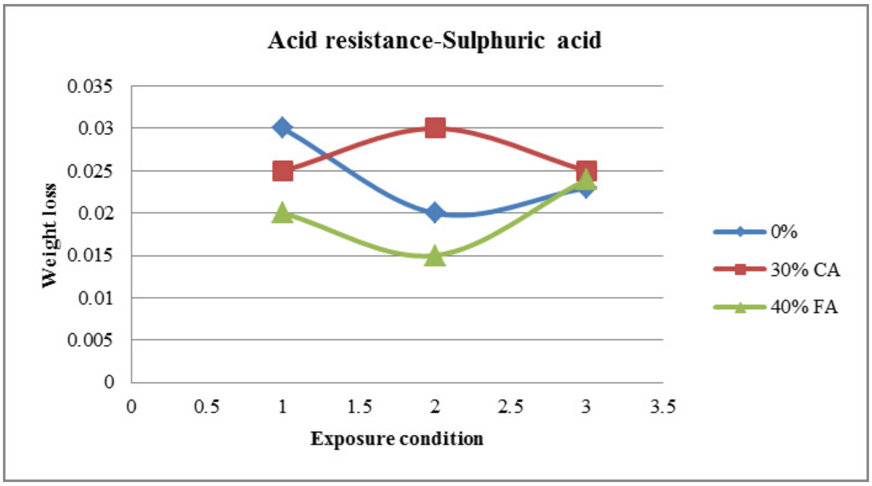

Fig. 4. Weight loss – Immersed in H_2SO_4

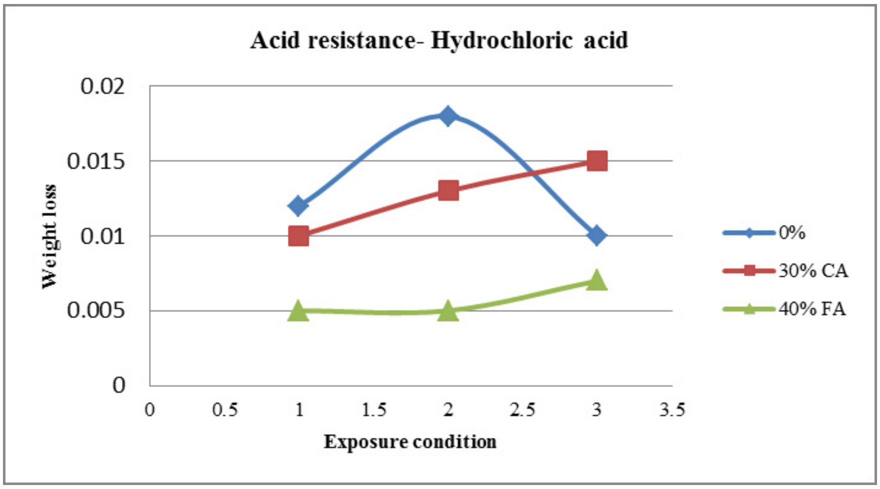

Fig. 5. Weight loss - Immersed in Hcl

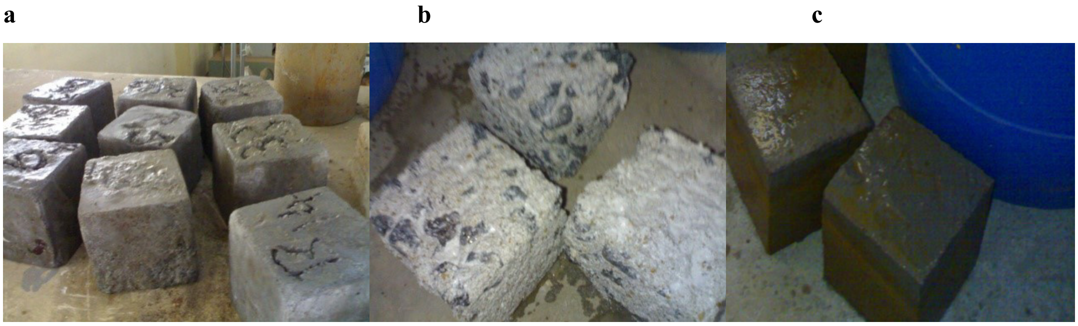

Fig. 6. (a) Before immersing in acid; (b) After immersing in H_2SO_4; (c) After immersing in Hcl

3.6 Deflection test

As the load increases, the deflection also increases gradually in RCC beams when partially replaced by steel slag in both coarse aggregate and fine aggregate form. Load deflection graph for both the percentage of replacement, compared with conventional concrete is shown in figure 7. RCC beams with steel slag shows almost the same deflection as conventional concrete.

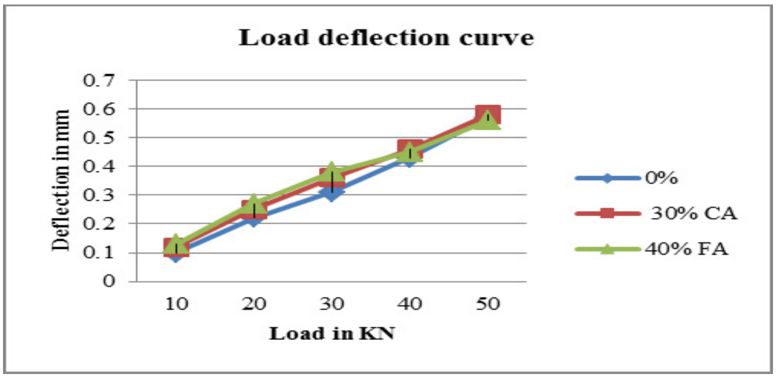

Fig. 7. Load deflection Curve

4. Conclusion

In this research, to investigate the possibility of replacing the conventional aggregates by steel slag, the strength and durability properties were studied. Compressive, tensile, flexural strength, rapid chloride penetration, acid resistance to Hcl, H_2SO_4 and deflection for concrete containing steel slag in coarse aggregate and fine aggregate individually were experimentally investigated. The preliminary study conclusions obtained are as follows.

- The optimum percentage of replacement for fine aggregate is 40% and for coarse aggregate is 30%, beyond which the compressive strength decreases on further replacement.
- Workability of concrete decreases as the percentage of replacement increases. Fine aggregate replacement shows better workability compared to coarse aggregate replacement.
- It was observed that the partial replacement of fine aggregate by steel slag improves the compressive tensile and flexural strength of concrete. Improvement in strength property was slightly lower for CA replacement when compared with FA replacement. Compressive strength increased on large number when both CA and FA were replaced by steel slag. But the flexural strength has slightly decreased for combined replacement [6].
- The weight loss in cubes after immersion in acids was very low. So, the concrete with partial replacement of CA and FA by steel slag shows better resistance to Hcl than to H_2SO_4.
- The penetration of chloride ion in rapid chloride penetrability is low for conventional concrete and 40% fine aggregate replacement concrete. Whereas, 30% coarse aggregate replacement comes under moderate penetrability. 40% FA replacement performs better than 30% CA replacement.
- Deflection in RCC beams gradually increases as the load on the beam increases for both the partial replacement. By adding steel slag to the aggregates, the resistance to deflection and vertical strain will increase [10]. Further researches can be carried out to improve the strength and acid resistance by the addition of some admixtures.

References

[1] Weiwu, Weide Zhang, Guowei Ma, Optimum content of copper slag as a fine aggregate in high strength concrete. Materials and Design 31(2010) 2878 – 2883.

[2] Furlani.E, Tonello.G, Maschio.S, Recycling of steel slag and glass cullet from energy saving lamps by fast firing production of ceramics. Waste management 30 (2010) 1714 – 1719.

[3] Carlo Pellegrino, Vittorio Gaddo, Mechanical and durability characteristics of concrete containing EAF slag as aggregate, Cement & Concrete composites 31(2009) 663 – 671.

[4] Bouikni.A, Swamy.R.N, Bali.A, Durability properties of concrete containing 50% and 65% slag. Construction and Building materials 23(2009) 2836 – 2845.

[5] Gambhir.ML, Concrete Technology. Tata McGraw Hill publishing company limited. 1986.

[6] Liuchunlin, Zha Kunpeng, Chen Depeng, Possibility of concrete prepared with steel slag as fine and coarse aggregates: A preliminary study. Procedia Engineering 4(2011) 412- 416.

[7] Afifudin.H, Nadzarah.W, Hamidah.M.S, Noor Hana.H,Microbial participation in the formation of calcium silicate hydrated (CSH) from Bacillus Subtilis.Procedia Engineering 20(2011) 159- 165.

[8] Aneta RAINOVA, Karel SEPS, Vladimira VYTLACILOVA, Possible use of the slag aggregate in fibre reinforced concrete. METAL(2012) 23-25.

[9] C.B.Echeta, E.E.Ikponmwosa,A.O.Fadipe, Effect of partial replacement of granite with washed gravel on the characteristic strength and workability of concrete. ARPN Journal of Engineering and Applied Sciences (2013) Vol.8,No.11.

[10] Ahmed Ebrahim Abu El-Maaty Behiry, Evaluation of Steel slag and crushed limestone mixtures as sub base material in flexible pavement. Ain shams Engineering Journal (2013) 4, 43-53.