DESIGN AND INVESTIGATION OF STEEL SLAG AS A PARTIAL REPLACEMENT FOR FINE AND COARSE AGGREGATE IN CONCRETE

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ABSTRACT

This paper presents the results of Design and investigations carried out to evaluate the effects of replacing fine and coarse aggregate with Steel slag on various concrete properties. The basic objective of this study is to identify the alternative source of good quality aggregates which is depleting very fast due to the fast pace of construction activities in India. Use of slag - a waste industrial byproduct of iron and steel production provides great opportunity to utilize it as an alternative to normally available aggregates. In this study, Concrete of M20 grade is considered for a W/C ratio of 0.55 for the replacements of 0, 10, 20, 30, 40, and 50% of both fine and coarse aggregates by steel slag. Whole study was done in two phases, i.e. replacement of normal crushed coarse aggregate with crystallized steel slag and replacement of natural fine aggregate with granular steel slag.

This project shows that replacing of natural aggregates by steel slag aggregates causes a negligible degradation in strength. It also shows that, as the amount of steel slag is increased beyond 75%, the workability of the concrete mixture became an important issue which eventually requires larger amounts of water reducing admixtures to achieve a minimum slump. The results showed that replacing about 30 to 40% of steel slag aggregates by volume for natural aggregates does not have any harm to concrete and also it will not have any adverse effects on the strength and durability.

INTRODUCTION

Concrete is the most widely used material on earth after water. Many aspects daily life depend directly or indirectly on concrete. Concrete is prepared by mixing various constituents like cement, aggregates, water, etc. which are economically available. Concrete is unique among major construction materials because it is designed specifically for particular civil engineering projects. Concrete is a composite material composed of granular materials like coarse aggregates embedded in a matrix and bound together with cement or binder which fills the space between the particles and glues those together. Concrete plays a critical role in the design and construction of the nation's infrastructure. Almost three quarters of the volume of concrete is composed of aggregates. To meet the global demand of concrete in the future, it is becoming a more challenging task to find suitable alternatives to natural aggregates for preparing concrete.

Natural aggregates are obtained from natural rocks. They are inert, filler materials and depending upon their size they can be separated into coarse aggregates and fine aggregates. The coarse aggregate fraction is that retained on 4.75 mm (No 4) sieve, while the fine aggregates fraction is that passing the same sieve. According to some estimates after the year 2012, the global concrete industry will require annually 12 to 15billionmetric tons of natural aggregates (U.S.G.S and nationalatlas.gov, accessed Nov 2008)..

The use of steel slag aggregates in concrete by replacing natural aggregates is a most promising concept. 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. Studies and tests are being conducted on ways to use this steel slag as an aggregate in concrete. According to the National Slag Association, steel slag is currently used in bituminous asphalt paving, the manufacture of Portland cement, and in roadway construction as a base course, along with some agricultural applications.

Purpose

The purpose of this project was to explore the feasibility of utilizing the steel slag produced by steel mills as a replacement for natural aggregate in the concrete. Steel slag aggregates generally exhibit the potential to expand due to the presence of Un hydrated free lime and magnesium oxides which hydrate in humid environments. If such a product is used in the concrete, it influences both the mechanical and physical properties of concrete along with its durability.

Scope

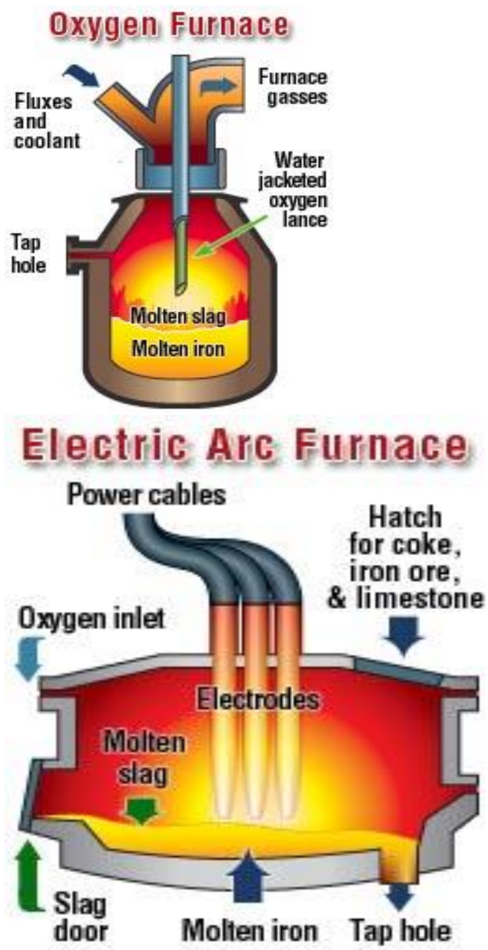
The original scope of this project was to investigate the properties of concrete with steel slag aggregates. The fresh and hardened properties of concrete were tested with steel slag aggregates. In addition to this several tests were also included such as compressive strength, split tensile strength and the flexural strength of concrete with steel slag aggregates.

Steel Slag and its production:

Steel slag is a byproduct obtained either from conversion of iron to steel in a Basic Oxygen Furnace (BOF), or by the melting of scrap to make steel in the Electric Arc Furnace (EAF). The molten liquid is a complex solution of silicates and oxides that solidifies on cooling and forms steel slag. Steel slag is defined by the American Society for Testing and Materials (ASTM) as .a non-metallic product, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminum, manganese, calcium and magnesium that are developed simultaneously with steel in basic oxygen, electric arc, or open hearth furnaces. (Kalyoncu, 2001).

The two states producing the most steel slag in the U.S. are Ohio and Indiana. The chemical composition and cooling of molten steel slag have a great effect on the physical and chemical properties of solidified steel slag. Steel furnace slag is produced in a Basic Oxygen Furnace (BOF) or Electric Arc Furnace (EAF) as a byproduct of the production of steel. In the Basic Oxygen Furnace(BOF), the hot liquid metal from the blast furnace, scrap and fluxes, which contain lime(CaO) and dolomitic lime, are charged to a furnace (Shi, 2004). A lance is lowered into the converter and then oxygen in injected with high pressure.

The electricity has no electrochemical effect on the metal, making it perfectly suited for melting scrap. During the melting process, other metals are added to the steel to give the required chemical composition. Mean while oxygen is blown into the EAF to purify the steel. This slag which floats on the surface of molten steel is then poured off.



Sketch of Basic oxygen furnace and Electric arc furnace

The main constituents of iron and steel slag are silica, alumina, calcium, and magnesia, which together make about 95% of the total composition. Minor elements included are manganese, iron, sulfur compounds and traces of several other elements (Kalyoncu, 2001). Physical characteristics such as porosity, density, particle gradation, are affected by the cooling rate of the slag and its chemical composition.

Current Uses of Steel Slag

Some of the current uses of steel slag according to the National Slag Association (NSA accessed, 2008) are as follows:

1. Steel slag is used as an ideal aggregate in hot mix asphalt (HMA) surface mixture application due to its high frictional resistance and skid resistance characteristics. The cubical nature of steel slag and its rough texture provides more resistance than round, smooth and elongated aggregates.
2. It is also used for manufacture of Portland cement.
3. It is used in base application, construction of unpaved parking lots, as a shoulder material, and also in the construction of beams and embankment.
4. It is also used in agriculture because it has minerals like iron, manganese, magnesium, zinc and molybdenum which are valuable plant nutrients.
5. It is environment friendly. During the production of cement, the CO2 emissions are reduced as slag has previously undergone the calcinations process.
6. Steel slag aggregates are used for soil stabilization or soil improvement material and for remediation of industrial waste water run-off.

Properties of Steel Slag

The United States Department of Transportation and the Federal Highway Administration along with the Turner Fairbank Highway Research Center (TFHRC) have listed some of the properties of steel slag:

Physical properties

Steel slag aggregates are fairly angular, roughly cubical pieces having flat or elongated shapes. They have rough vesicular nature with many non-interconnected cells which gives a greater surface area than smoother aggregates of equal volume; this feature provides an excellent bond with Portland cement (NSA accessed Nov 2008).Steel slag has a high degree of internal friction and high shear strength.

1. They are strong and durable.
2. They have excellent angular shape which helps to develop very strong Interlocking properties.
3. They have high resistance to abrasion and impact.

Physical properties of steel slag.

S.No.	Property	Value
1	Specific Gravity	3.2-3.6
2	Approx Dry Rodded unit weight kg/m^3	1600-920
3	Water Absorption	Up to 3%

Chemical and Mineralogical composition

Blast furnace slag usually contains four major oxides, namely lime, magnesia, silica and alumina. Minor elements include sulfur, iron, manganese, alkalis and trace amount of several others. The chemical composition of slag is generally expressed in terms of simple oxides calculated from elementary analysis determined from x-ray fluorescence. Most of the blast-furnace slag produced in the U.S. has compositions within the ranges as shown in table II.

The rate of cooling of steel slag is generally kept lower so that the crystalline compounds are formed. The predominant compounds in steel slag are dicalcium silicate, tricalcium silicate, dicalcium ferrite, merwinite, calcium aluminates, calcium-magnesium iron oxides, some free lime and magnesia. Steel slag is mildly alkaline, with a solution pH generally in range of 8 to 10.

Past studies on Steel Slag aggregates

The successful incorporation of steel slag as an aggregate in concrete has been studied in the past. Steel slag is an industrial byproduct and instead of disposing it in the landfill, the use of such product in the construction market would increase efficiency and economy. The physical and chemical characteristics of steel slag have been examined carefully. Due to its potentially expansive properties, it require special care if used in construction or other specific applications. The possibility of utilizing such product as a concrete aggregates with ecological benefits has been globally studied by several researchers like Anastasiou and Papayianni, (2006).They conducted several tests with slag aggregates in concrete and found out that the 28 day strength was increased by 21% with replacement of natural aggregates, while there was no increase in the setting time of concrete mixtures. The cement-aggregate interface seemed to be very dense without cracks or other discontinuities. The concrete that is produced with steel slag aggregates is of high specific gravity compared to conventional concrete. However the specific gravity can be increased or reduced proportionally by the combination of different types of aggregates (Anastasiou and. Papayianni, 2006).

A study on durability of the concrete made with Electric Arc Furnace slag as an aggregate was done by Manso and Gonzalez (2004), and the results showed that it was acceptable. The concrete mixes using conditioned EAF slag showed good fresh and hardened properties and acceptable behavior against aggressive environmental conditions. It was observed that the compressive strength was similar to that of traditional concrete. The durability was slightly lower than conventional concrete.

Mix proportions

The mix proportions were made for a control mix of slump 100 ± 25 mm for M20, grade of concrete for w/c ratio of 0.55respectively by using IS-10262- 2009 method of mix design. Total five mixes were made by replacing normal crushed course aggregate and fine aggregate with Slag keeping w/c ratio as constant (control mix) by 0, 10, 20, 30, 40 and 50 % replacements given in table .

Material Investigations

Introduction

Material investigation is done to test the various materials that are used in making concrete cubes. According to these test results obtained we designed the mix ratios for the materials and prepared the concrete cubes, beams and cylinders. The information are given below,

Cement

OPC of 53 grades in one lot was procured and stored in air tight container. The cement used was fresh i.e. used within three months of manufacture. It should satisfy the requirement of IS12262. The properties of cement are determined as per IS4031:1968 & results are tabulated.

Properties of Cement

S.No	PROPERTIES	VALUES
1	Fineness	10%
2	Initial setting time	28min
3	Final setting time	2-3hours
4	Standard consistency	29%
5	Specific gravity	3.15

Aggregates

A fine aggregate obtained from the river is used for experimental purpose. The less amount of clay and silt (<3% by weight). The hire from silt, clay, salt and organic material and it was clean and dry. It is of size retained in 1.19 micron sieve.

The coarse aggregate is strongest and porous component of concrete. Presence of coarse aggregate reduces the drying shrinkage and other dimensional changes occurring on account of movement of moisture. The coarse aggregate used passes in 19 mm and retained in 11.4mm sieve. It is well graded (should of different particle size and maximum dry packing density and minimum voids) and cubical in shape

Steel Slag

For this investigation, Steel Slag from local steel Refining plant, (Agni Steel Pvt. ltd) is obtained with its physical and chemical properties as tabulated below

Water

Ordinary drinking water available in the construction laboratory was used for casting all specimens of this investigation. Water helps in dispersing the cement even, so that every particle of the aggregate is coated with it and brought into ultimate contact with the ingredients.

It reacts chemically with cement and brings about setting and hardening of cement. It lubricates the mix and compact property. Potable water, free from impurities such as oil, alkalis, acids, salts, sugar and organic materials were used. The quality of water was found to satisfy the requirement if IS456-2000.

CASTING AND CURING

Introduction

The mould specification, preparation of mould the method of casting and curing are discussed in following

Casting

Mould Preparation

The cube mould was placed in position on an even surface. All the interior faces and sides were coated with mud oil to prevent the sticking of concrete to the mould.

Mixing

The concrete using grade M20 (1:1.808:3.85) with water cement ratio 0.55 were used. Concrete is mixed in roller type of mixing machine.

Placing

Concrete is properly placed beneath and along the sides of the mould with help of trowel.

Compaction

Hand compaction was done for all the cubes used in the test. The damping mild steel rods having point ends were used to poke the concrete and it is placed in vibrating table to make compaction complete. Used to poke the concrete and it is placed in vibrating table to make compaction complete.

Curing

The mould is striped after 24 hours. The test cubes were cured for duration of 7 and 28 days in a curing tank. After the wet curing the specimens were air cured for minimum period 2 Hours under laboratory conditions.

TESTING AND ANALYSIS OF SPECIMEN

Introduction

Testing of concrete plays an important role in controlling and confirming the quality of cement concrete. Cube, beam and cylinder are tested for its strength characteristics.

Testing Of Specimen

Compressive Strength Test

The cubes of size 150x150x150mm are placed in the machine such that load is applied on the opposite side of the cubes as casted. Align carefully and load is applied, till the specimen breaks. The formula used for calculation

Compressive Strength= Total Failure Load / Area of the Cube

Split Tensile Test

The test is carried out by placing cylinder specimen of dimension 150mm diameter and 300mm length, horizontally between the loading surface of compression testing machine and the load is applied until failure of the cylinder along the vertical diameter. The failure load of the specimen is noted.

The failure load of tensile strength of cylinder is calculated by using the formula

Tensile strength = 2P / 3.14 DL

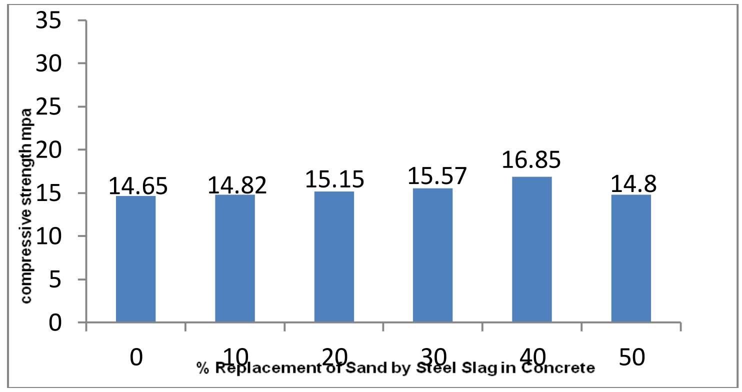
Split Tensile test on concrete Cylinder

Flexural Strength Test

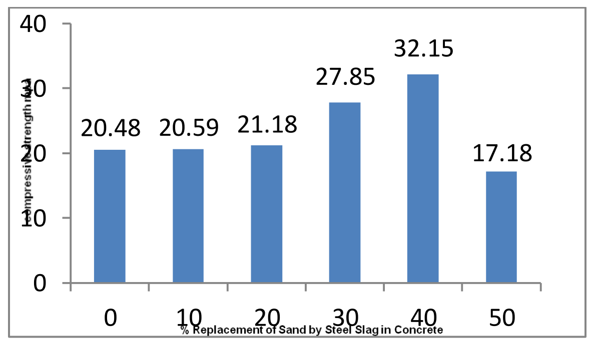
The test is carried out to find the flexural strength of the prism of dimension 100 x 100 x 500 mm. The prism is then placed in the machine in such manner that the load is applied to the uppermost surface as cast in the mould. Two points loading adopted on an effective span of 400 mm while testing the prism .The load is applied until the failure of the prism. By using the failure load of prism

Flexural strength = PL/bd^2

Compression test on concrete Prism



Compressive Strength of Concrete for
7 days
Fine aggregate replacement



Compressive Strength of Concrete
for 28 days
Fine aggregate replacement

TEST RESULT ANALYSIS

General

A total of 72 cubes, 36 beams and 36 cylinders were casted and tested, and there compressive strength, split tensile strength and flexural strength results have been taken and compared with the conventional specimens of M30 grade design mix.

Compression Strength Results:

It has been observed that the concrete produced from 0%, 10%, 20%, 30%, 40%, and 50%replacement of natural fine aggregate by Steel Slag as Coarse and Fine Aggregate, shows maximum compressive strength as compared to other replacement. The optimum strength of concrete is 40% for Steel Slag as Replacement of Sand. And 30% for Steel Slag as Replacement of Coarse aggregate. Compressive Strength result for fine aggregate replacement

S.No	% of Natural sand	% of Steel Slag for sand	Compressive strength Mpa (7days)	Compressive strength Mpa (28days)
1	100	0	14.65	20.48
2	90	10	14.82	20.59
3	80	20	15.15	21.18
4	70	30	15.57	27.85

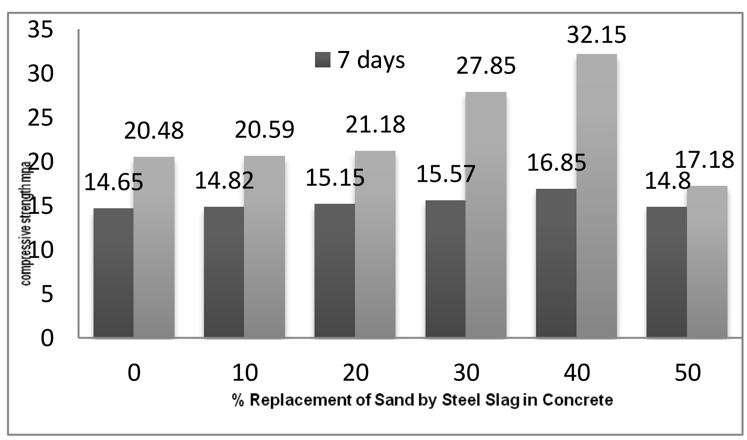
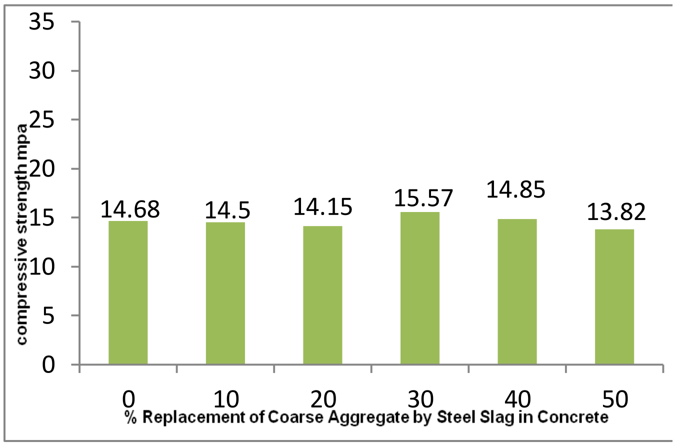
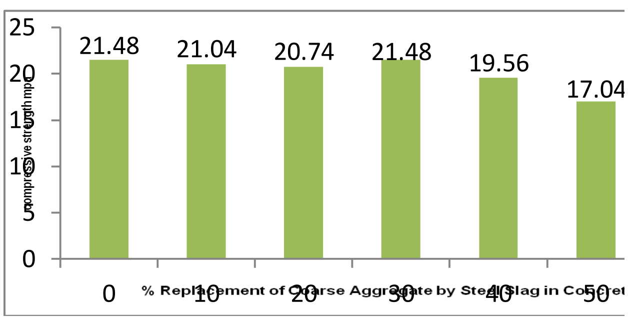


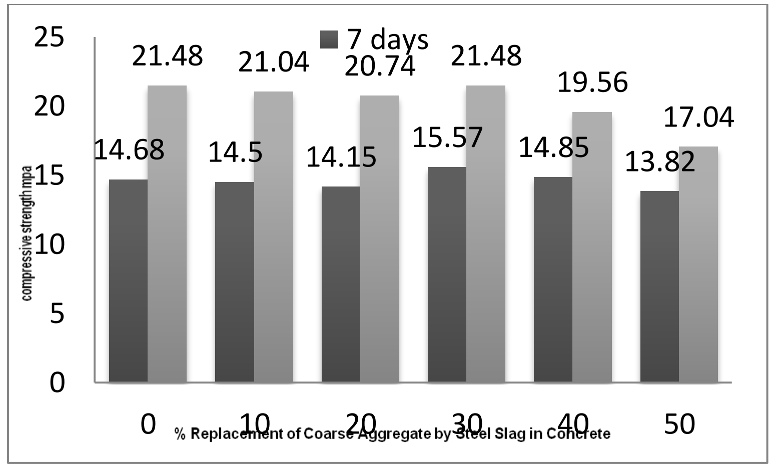
Figure 07: Comparison of Compressive Strength of Concrete for 7 & 28 days



Compressive Strength of Concrete for 7days
Coarse aggregate replacement



Compressive Strength of Concrete for 28 days
Coarse aggregate replacement



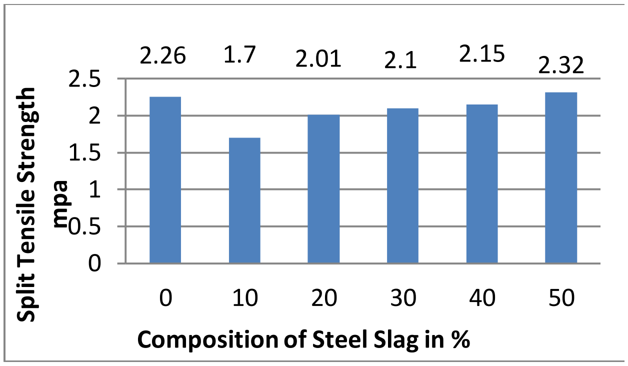
Comparison of Compressive Strength of Concrete for 7 & 28 days

Split Tensile Strength Results:

It has been observed that the concrete produced from 0%, 10%, 20%, 30%, 40%, and 50% replacement of natural fine aggregate by Steel Slag, shows maximum compressive strength as compared to other replacement. The optimum strength of concrete is 30%.

Split Tensile Strength result for fine aggregate replacement

S.no	% of Natural Sand	% of Steel Slag	Split Tensile strength N/mm^2
1	100	0	2.26
2	90	10	1.70
3	80	20	2.01
4	70	30	2.1
5	60	40	2.15
6	50	50	2.32

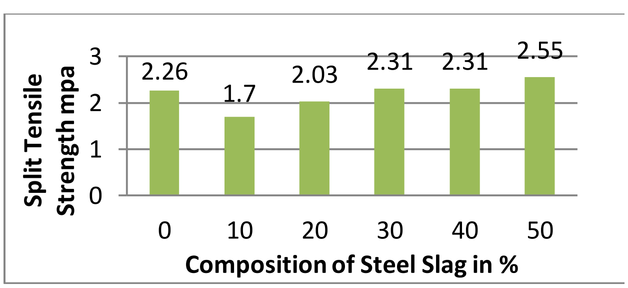


Split Tensile Strength of Concrete for 28 days

Fine aggregate replacement

Split Tensile Strength result for Coarse aggregate replacement

S.no	% of Natural Coarse	% of Steel Slag	Split Tensile strength N/mm^2
1	100	0	2.26
2	90	10	1.70
3	80	20	2.03
4	70	30	2.31
5	60	40	2.31
6	50	50	2.55



Split Tensile Strength of Concrete for 28 days

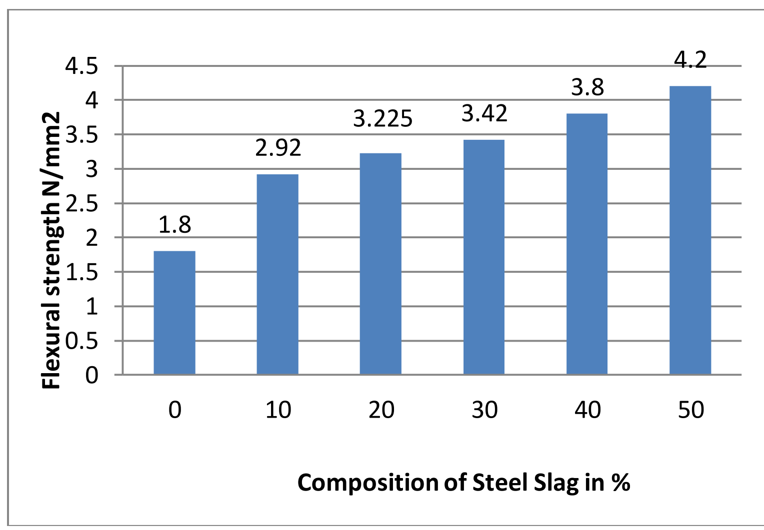
Coarse aggregate replacement

Flexural Strength Results

It has been observed that the concrete produced from 0%, 10%, 20%, 30%, 40%, and 50% replacement of natural fine aggregate and Coarse aggregate, shows maximum compressive strength as compared to other replacement. The optimum strength of concrete is 40%.

Table 14: Flexural Strength Results for Fine aggregate replacement

S.no	% of Natural sand	% of Steel Slag	Flexural strength N/MM^2 (28days)
1	100	0	1.80
2	90	10	2.92
3	80	20	3.225
4	70	30	3.420
5	60	40	3.80
6	50	50	4.20



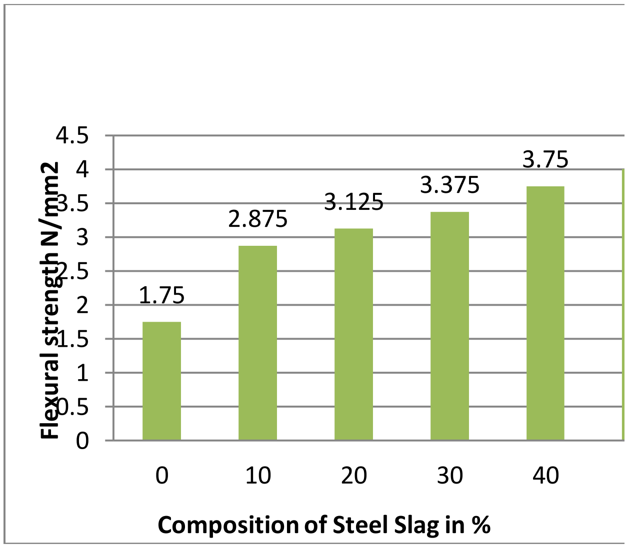
Flexural Strength of Concrete for 28 days

Fine aggregate replacement

Flexural Strength Results for Coarse aggregate replacement

S.no	% of Natural coarse	% of Steel Slag	Flexural strength N/MM^2 (28days)
1	100	0	1.75

2	90	10	2.875
3	80	20	3.125
4	70	30	3.375
5	60	40	3.75
6	50	50	4



Flexural Strength of Concrete for 28 days

Coarse aggregate replacement

CONCLUSION

Summary

From the experimental results obtained on the replacement of fine and coarse aggregate partially by steel slag on concrete, the following conclusions are drawn as below,

1. The study concluded that compressive strength of concrete improved by 4 to7 % at the % replacements of normal crushed coarse aggregate with crystallized slag. In case of replacements of fine aggregate, the strength improvement was notably observed at 30 to 50 % replacement level by 4 to 6%.
2. It could be said that full substitution of slag aggregate with normal crushed coarse aggregate improved the flexure and split tensile strength at 40% of replacement by 6 to 8% and in case of replacing fine aggregate with slag, the strength improvement was at 30 to 50 % replacement levels by 5 to 6%.

Hence, it could be recommended that slag aggregate could be effectively utilized as coarse and fine aggregate in all concrete applications as a partial replacement of normal crushed coarse up to 30% and natural fine aggregate up to 40%

Suggestions for future research

1. A much more extensive field study on a concrete structure made with steel slag aggregates used in the mixture should be conducted and changes in durability and mechanical properties should be investigated and correlated to laboratory results.
2. Further investigation on resistance of concrete with steel slag aggregates to attack by sulfates; alkali silica reactions, carbonation, sea water attack, harmful chemicals and resistance to high temperatures are needed. The behavior of steel slag aggregate concrete under corrosive environments and its fire resistance capacity should also be investigated. The results of such studies would directly benefit the construction industry and broader use of steel slag in concrete would improve overall properties and cost effective solution.
3. The long term behavior of concrete with steel slag aggregates should be studied and its compatibility with

reinforcing steel should be analyzed in the future.

4. A comprehensive chemical analysis of steel slag aggregates should to be carried out before using in construction.
5. Due to presence of several dangerous heavy metals and salts in the steel slag aggregates, leaching tests should be carried out to verify its environmental compatibility.

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