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Mechanical Properties of Concrete with Replacement of Steel Slag as Coarse Aggregate

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ABSTRACT

Steel slag is a byproduct of the steelmaking and steel refining processes Presently in India, due to limited modes of practices of utilization, huge amount of iron and steel slag dumped in yards of each production unit and engaging of important agricultural land and grave pollution to whole environment. This review presents utilization trends of steel slag and possible potentials for large-scale employment of steel slag in Indian context.

This project aim is to study experimental investigation about the effect of partial replacement of coarse aggregates by steel slag (SS), on the various strength and durability properties of concrete, by using the mix design of M30 grade. The optimum percentage of replacement of coarse aggregate by steel slag is found

This study is carried out to determine the feasibility of using steel slag as partial replacement for coarse aggregates of M30 grade with different replacement percentages i.e. (0%, 25%, 50%, 75%&100%) .

In this present study, physical and chemical characteristics of steel slag are to be analyzed and then the research progress of steel slag with natural aggregate concrete cubes, cylinders and beams are to be casted by using mix design M30 and are cured for 7, 28 & 56 days. The mechanical, durability properties of hardened concrete is to be carried out according to IS codes. For mechanical properties of concrete (i.e. compressive strength, Split tensile strength & Flexural strength) are to be determined and durability properties like acid attack, drying shrinkage, indirect carbonation, also need to be investigated. And after that will addition with fibers for maximum strength attained mixes of steel aggregate replacement mixes. By comparing the test results it may be concluded that steel slag may be used as replacement of natural coarse aggregate inconcrete.

1. INTRODUCTION

General

Sustainability is important for the well-being of our planet and continuous human development. Concrete is amongst one of the most widely used construction materials in the world. Waste utilization can serves as an attractive alternative to disposal. Nowadays, the major problem in the construction industry is the non-availability of coarse aggregate and it has compelled the researchers to think about some alternate option .High performance concrete is a construction material which is being used in increasing volumes in recent year due to its long term durability, performance and batter rheological and mechanical properties than conventional concrete. An efficient approach to overcome these problems is the slag utilization. In an integrated steel plant, 2 to 4 tonnes of wastes (including solid, liquid and gas) are generated for every tonne of steel produced. Among all the solid/liquid wastes, slags generated at iron making and steel making units are created in the largest quantities. With increasing capacities, disposal of large quantities of slag becomes a big environmental concern and a critical issue for steel makers.

Current total productions of steel slag in India, are around 12 million tonnes per annum (Indian Minerals Yearbook, May 2016). Slag is a by-product generated during manufacturing of pig iron and steel. It is produced by action of various fluxes upon gangue materials within the iron ore during the process of pig iron making in blast furnace and steel manufacturing in steel melting shop. Primarily, the slag consists of calcium, magnesium, manganese and aluminium silicates in various combinations. The cooling process of slag is responsible mainly for generating different types of slags required for various end-use consumers. Although, the chemical composition of slag may remain unchanged, physical properties vary widely with the changing process of cooling. Presently in India, due to limited modes of practices of utilization, huge amount of iron and steel slag dumped in yards of each production unit and engaging of important agricultural land and grave pollution leading to the serious pollution to the environment.

Concrete is amongst one of the most widely used construction materials in the world. Nowadays, the major problem in the construction industry is the non-availability of coarse aggregate and it has compelled the researchers to think about some alternate option. Utilization of industrial by-product has become an attractive alternative to disposal. An efficient approach to overcome these problems is the slag utilization. It is an environmental application since the reuse or recovery of this material provides environmentally related benefits.

Scope and objectives

The scope of this project is to determine the feasibility of using steel slag as partial replacement for coarse aggregates of M30 grade with different replacement percentages of aggregates. The main objective of present study is to achieve the target strength in M30 grade with different replacement percentages i.e. (0%, 25%, 50%, 75% &100%) and study their compositions.

1. Characterization of materials i.e. cement, coarse aggregate and steel slag.
2. Design M30 grade of concrete with Steel Slag as Partial or complete replacement of Coarse Aggregates.
3. To study the mechanical properties of concrete with coarse aggregate replaced with steel slag at percentage of 0%, 25%, 50%, 75%, and 100% and to find out the optimum percentage replacement.

2. REVIEW OF LITERATURE

1) Literature Reviewed

Liwu Mo et.al [1] studied 60% of steel slag powders containing high free-CaO content, 20% of Portland cement and up to 20% of reactive magnesia and lime were mixed to prepare the binding blends. The binding blends were then used to cast concrete, in which up to 100% of natural aggregates (limestone and river sands) were replaced with steel slag aggregates. The concrete was exposed to carbonation curing with a concentration of 99.9% CO2 and a pressure of 0.10 MPa for different durations (1d, 3d, and 14d). The carbonation front, carbonate products, compressive strength, microstructure, and volume stability of the concrete were investigated. Results show that the compressive strength of the steel slag concrete after CO2 curing was significantly increased. The compressive strengths of concrete subjected to CO2 curing for 14d were up to five-fold greater than that of the corresponding concrete under conventional moist curing for 28d. By replacement of limestone and sand aggregates with steel slag aggregates also increased the compressive strengths of the concrete subjected to CO2 curing.The author study provides a potential approach to prepare concrete with low-carbon emissions via the accelerated carbonation of steel slag.

Liu Chunlin et.al [2] investigate the possibility of replacing the traditional aggregates for concrete production. Compressive and flexural strength, volume deformation of concrete containing EAF slag as aggregate were experimentally investigated by strength test according to the specification of GB/T 50081-2002 and unrestrained specimens volume deformation test. The test results indicate that the mechanical strength of steel slag concrete is acceptable, though slightly lower flexural strength than that of conventional concrete and the expansion induced form steel slag using as both coarse and fine aggregates in concrete may lower the shrinkage and expansion to a certain extent. In accordance with the experimental phase the author preliminary study conclusions are the strength performance of EAF slag concretes is similar to that of a more traditional concrete, with a higher compressive strength and a slightly less flexural strength and the volume deformation of SSAC shows dilatometric effect (less shrinkage) comparing with the conventional concrete. However, further researches must be investigated thoroughly for the theory and application of scrap tire particle modified steel slag aggregates concrete.

Ivanka Netingera et.al [3] experimental study of the residual properties of the mixtures prepared with slags available from the Croatian steel plants after their exposure to high temperatures was performed and the results were compared with the same properties of the reference concrete made of dolomite. Electric arc furnace (EAF) steel slag as by-products from the steel production industry is considered as an aggregate which could improve post-fire properties of concrete due to the fact that it is the material that is made at the temperatures of up to 1650 °C. At the age of 56 days concrete specimens have been exposed to high temperatures up to 800 °C. Upon cooling of the specimens their residual properties (compressive strength, modulus of elasticity, weight loss and ultrasonic pulse velocity) were tested and compared with the same properties of the reference concrete. Microstructural analysis based on SEM observations was also done. The obtained results showed that slag could improve fire performance of concrete in the temperature range up to 400 °C. The improvement was especially prominent in the case of the mixtures prepared with previously thermally treated slag where relative residual compressive strength was increased up to 16% at the temperature of 400 °C.

V. Subathra Devia et.al [4] 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. The author investigate the possibility of replacing the conventional aggregates by steel slag, the strength and durability properties were studied.Compressive strength, tensile strength, flexural strength and durability tests such as acid resistance, using Hcl, H2SO4, and Rapid chloride penetration, are experimentally investigated. The test 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 preliminary study conclusions obtained from author study are 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. Improvement in strength property was slightly lower for CA replacement when compared with FA replacement. But the flexural strength has slightly decreased for combined replacement. So, the concrete with partial replacement of CA and FA by steel slag shows better resistance to Hcl than to H2SO4 and 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. Further researches can be carried out to improve the strength and acid resistance by the addition of some admixtures.

Ivana Barisic et.al [5] investigated about the new type of low-strength concrete made with steel slag and gravel. The aim of the author study was to identify possible applications of slag as aggregates in cement-stabilized base courses to reduce the consumption of natural materials and cement, as well as to introduce the new aggregate into Croatian road-construction practices. For these purposes, the following basic engineering properties of these layers were determined for fifteen different mixtures: optimum water content, density, compressive strength and indirect tensile strength. Three different amounts of binder (2%, 4%, and 6%) and two types of aggregates (steel slag and gravel) were used. Additionally, the compressive and indirect tensile strength of the concrete increased with curing age. The strength of mixes with low cement contents increased with the slag content, while that of mixes with higher cement contents decreased with slag content. Finally, the average indirect tensile strength for all mixes as a percentage of compressive strength was 14%. The results of the author study could greatly influence the use of this non-traditional aggregate, which can now be technically and economically justified as components in stabilized base courses and used as coarse aggregate.

Ahmed Ebrahim Abu El-Maaty Behiry [6] study is carried out to investigate the effect of using steel slag mixed with limestone aggregate on increasing the density and strength of sub base layer. Second objective of the author research is studying the effect of steel slag on the resisting of failure factors such as deflection, stress and strain and determining the optimal steel slag ratio. The results obtained from the author study indicated that the mechanical characteristics, and the resistance factors were improved by adding steel slag to the crushed limestone. By Increasing the steel slag percentage (SSP) to the limestone in the blended mix increases the mechanical properties .The best density and strength for the layer with the least construction costs obtained at a blended mix of 70% steel slag percentage to 30% limestone. Thus, the author research recommends utilizing industrial by-products such as steel slag especially in developing countries to reduce the use of primary aggregate and thus minimize the cost of road construction.

George Wanga [7] investigated about the Expansion force and autoclave disruption tests for measuring the expansion force generated by coarse steel slag aggregate. Equations are deduced to convert the measured expansion force to expansion force of unit volume slag and an individual slag particle. The tension stresses of steel slag particles, 0.64–1.28 MPa, are used to quantitatively evaluate the stability of steel slag and related to the tensile stress of cement mortar matrix. Based on the results and modeling, the inherent relationship between the expansion force of steel slag and the allowable stress of a rigid matrix is revealed. Based on the analysis, preliminary laboratory testing and comparison, the maximum expansion force is useful to evaluate and decide if a given steel slag is suitable for use in a given matrix with a constrained stress. Even though there is some positive stability and strength related results for steel slag concrete samples, each specific slag should be fully quantified and checked for each specific use as there are limited quantitative guidelines. At this stage, author concluded that it is imperative that only special quality slag, of clearly proven suitability, is considered for concrete aggregate and confined application uses.

Wang Qiang et.al [8] investigated about the influence of steel slag on the compressive strength, drying shrinkage, permeability to chloride, and carbonation resistance of concrete under two different conditions: constant W/B and constant 28 days' compressive strength. The results show that under the condition of constant W/B, increasing the steel slag replacement tends to decrease the compressive strength (especially the early strength), increase the permeability, and decrease the anti-carbonation ability of concrete. The negative effect of steel slag on the compressive strength, permeability, and carbonation resistance of concrete is weaker at lower W/B. At high W/B, steel slag tends to accelerate the development of drying shrinkage at the early ages, but it has an insignificant influence on the ultimate shrinkage at 90 days. At low W/B, steel slag has little influence on the drying shrinkage of concrete. Under the condition of constant 28 days' compressive strength, the concrete with steel slag exhibits lower early strength but higher late strength than the pure cement concrete. Finally, the concrete with steel slag can get permeability, drying shrinkage, and carbonation resistance similar to the pure cement concrete.

Critical review (identification of gap)

- From all the above literature reviews there is need to be investigated about the durability properties of all concrete mixes contain steel slag as coarse aggregate with different replacement percentages i.e. (0%, 25%, 50%, 75% &100%) and study their compositions.

3. METHODOLOGY

Physical properties of cement.

SNO	Description of test	IS code
1	Specific Gravity	IS 4031-1988(part-11)
2	Fineness	IS 4031-1996(part-1)
3	Standard consistency	IS 4031-1988 (part-4)
4	Initial Setting time	IS 4031-1988 (part-5)
5	Final setting time	IS 4031-1988 (part-5)

Physical properties of fine aggregate

SNO	Description of test	IS code
1	Specific Gravity	IS 2386-1963 (part-3)

2	Fineness Modulus	IS 2386-1963 (part-3)
3	Bulk density	IS 2386-1963 (part-3)
4	Water absorption	IS 2386-1963 (part-3)

Physical properties of coarse aggregate

S.No	Description of test	IS code
1	Specific Gravity	IS 2386-1963 (part-3)
2	Water absorption	IS 2386-1963 (part-3)
3	Bulk density	IS 2386-1963 (part-3)
4	Flakiness Index	IS 2386-1963 (part-1)
5	Elongation Index	IS 2386-1963 (part-1)
6	Aggregate Impact value	IS 2386-1963 (part-4)
7	Aggregate Crushing Value	IS 2386-1963 (part-4)

Chemical Properties of Steel slag

SNO	Chemical Components	Values Obtained	Limits as per (IS code & (ASTM)
1	%MnO	12.45	2-15
2	%SiO2	42.11	30-40
3	%FeO	0.84	3
4	%Al2O3	10.36	8-18
5	%CaO	24.68	40-50
6	%MgO	6.12	0-8
7	Basicity	0.731	2

Design mix for M30 Grade concrete.

SNO	Description of test	IS code
1	Concrete mix-proportioning	IS 10262-2009

Methodology for Mechanical properties of Hardened concrete

S.NO	Description of test	IS code
1	Compressive strength	IS 516-1959
2	split tensile strength	IS 5816
3	Flexure strength	IS 516-1959

Mix Design of M30 Grade concrete with different percentage of SMS (silico- manganese steel slag)

- To study the mechanical properties of concrete mix of M 30 at 0%, 25%, 50%, 75%, 100% replacement of natural aggregate with steel slag as coarse aggregate.

Mix designation		MIX S	MIX 1	MIX 2	MIX 3	MIX 4	Units
Cement		100	100	100	100	100	%
Fine aggregate		100	100	100	100	100	%
Coarse aggregate	**20 mm (70%)**	100	75	50	25	0	%
	10 mm (30%)	100	100	100	100	100	%
Steel slag		0	25	50	75	100	%
Normal water		100	100	100	100	100	%
Sp		100	100	100	100	100	%

Casting of specimens:

Casting of natural aggregate and steel slag aggregate concrete for the mix- proportion of M30 by using cubes.

Number of Specimens to be casted for compression test, 14 and 28days

	MIX DESIGNATION				
	MIX S	**MIX 1**	**MIX 2**	**MIX 3**	**MIX 4**
7 DAYS	**3**	**3**	**3**	**3**	**3**
14 DAYS	3	3	3	3	3
28 DAYS	3	3	3	3	3
TOTAL	**45 CUBES**				

Number of Specimens to be casted for split tensile test, 14 and 28days

	MIX DESIGNATION				
	MIX S	**MIX 1**	**MIX 2**	**MIX 3**	**MIX 4**
7 DAYS	**3**	**3**	**3**	**3**	**3**
14 DAYS	3	3	3	3	3
28 DAYS	3	3	3	3	3
TOTAL	**45 CYLINDERS**				

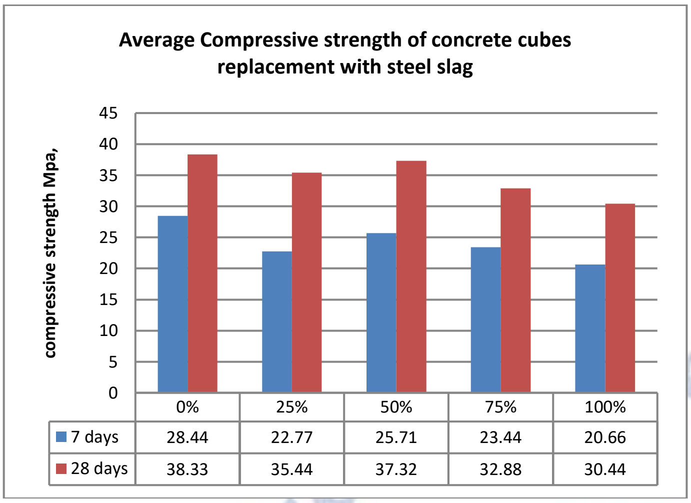
Number of Specimens to be casted for Flexural strength test, 14 and 28days

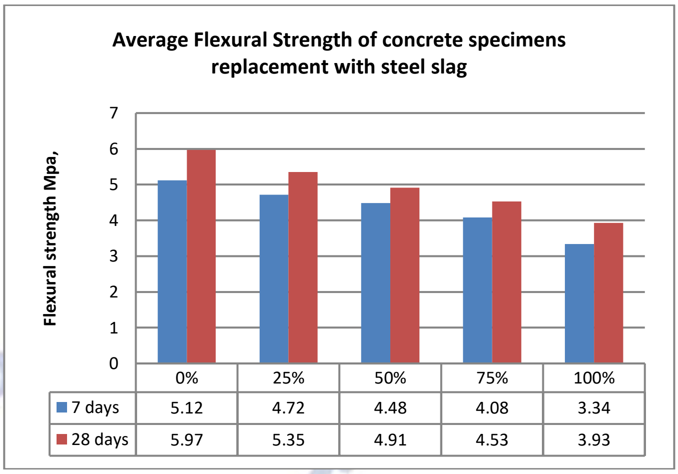
	MIX DESIGNATION				
	MIX S	**MIX 1**	**MIX 2**	**MIX 3**	**MIX 4**
7 DAYS	**3**	**3**	**3**	**3**	**3**
14 DAYS	3	3	3	3	3
28 DAYS	3	3	3	3	3
TOTAL	**45 BEAMS**				

4. RESULTS AND DISCUSSIONS

Average Compressive strength of concrete cubes replacement with steel slag

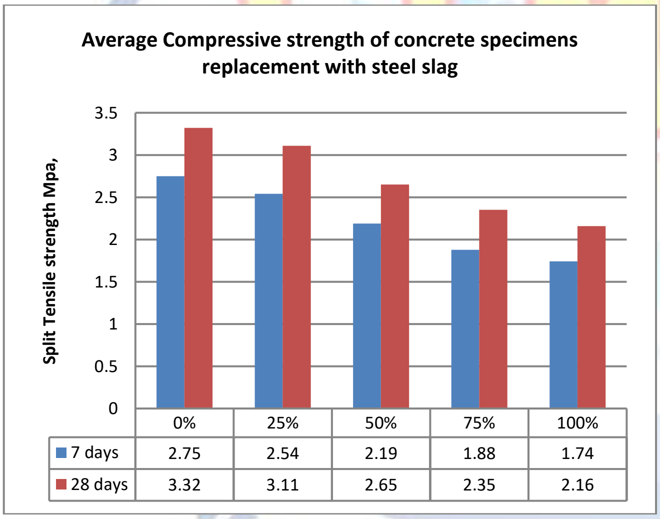
S.No	Mix designation	Compressive strength (MPa)	
		7 days	**28 days**
1	MIX S	28.44	38.33
2	MIX 1	22.77	35.44
3	**MIX 2**	**25.71**	**37.32**
4	MIX 3	23.44	32.88
5	MIX 4	20.66	30.44





Average Split tensile strength of specimen's replacement with steel slag

S.No	Mix designation	Split Tensile strength (MPa)	
		7 days	28 days
1	MIX S	2.75	3.32
2	**MIX 1**	**2.54**	**3.11**
3	MIX 2	2.19	2.65
4	MIX 3	1.88	2.35
5	MIX 4	1.74	2.16



Average Flexural Strength of concrete specimen's replacement with steel slag

S.No	Mix designation	Flexural strength (MPa)	
		7 days	28 days
1	MIX S	5.12	5.97
2	**MIX 1**	**4.72**	**5.35**
3	MIX 2	4.48	4.91
4	MIX 3	4.08	4.53
5	MIX 4	3.34	3.93

5. CONCLUSIONS

From the experimental works carried out, the following conclusions are made.

- This experimental study has proved to be better way to disposal of steel slag.
- The results showed that it has properties similar to natural aggregates and it would not cause any harm if incorporated into concrete and has no negative effects on the properties of hardened concrete.
- The optimum percentage of steel slag was found to be 50%.
- The Compressive strength, flexural strength and splitting tensile strength for steel slag aggregates concrete were similar to conventional concrete. The strength may be affected with time and so long term effects on hardened properties of concrete require further investigation.
- When this optimized value will be used, it will give better strength and more durable concrete when compared to control concrete and saves material cost.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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