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REPLACEMENT OF STEEL SLAG AS COARSE AGGREGATE IN CONCRETE MIXTURE LEADS TO A HEAVY DENSITY CONCRETE

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Abstract— The main scope of this research is to investigate the properties of concrete with steel slag coarse aggregates. The tests to be conducted are workability and strength of the concrete like compressive test, split tensile strength and flexural strength. Durability of concrete with steel slag coarse aggregate concrete is also to be included. The percentage replacement of coarse aggregate will be done in 25%, 50%, 75% and 100% by the steel slag aggregate. Thus replacing the natural coarse aggregate in concrete applications with steel slag would lead to considerable environmental benefits and would be economical.

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. The purpose of this research is to explore the feasibility of utilizing the steel slag produced by steel industries as a replacement for natural coarse aggregate in the concrete.(Abdullah A. Almusallam, 2004)

INTRODUCTION

1.1 General

Concrete plays a major role in the design and construction of infrastructures. One third of the volume of concrete is composed by coarse aggregate and fine aggregates. The scarcity of the building material is increased every day. To meet this demand of building materials in future, it is necessary to find the suitable alternatives for preparing concrete. Therefore, the available natural aggregates and waste materials from industry are becoming increasingly important.

Natural aggregates are obtained from natural rocks. They are inert, filler materials and depending upon their size they can be separated in to coarse aggregates and fine aggregates. Preventing the depletion of natural resources and enhancing the usage of waste materials has become a challenge to the scientist and engineers. A number of studies have been conducted concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using this waste material.(NSA, 2003)

Slag is a product of the iron and steel making process. Iron cannot be prepared in the blast furnace without the production of its co-product; blast furnace slag. Similarly, steel cannot be prepared in the Basic Oxygen Furnace (BOF) or in an Electric Arc Furnace (EAF) without making its co-product; steel slag [www.nationalslag.arc]. Steel industries in India are producing about 12million tones of steel per year. The use of steel slag aggregates in concrete by replacing natural coarse aggregates is a most promising concept. (Joseph O. Akinmusuru 1991) 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 to use this steel slag as an aggregate in concrete [Huang Yi, GuopingXu, HuigaoCheng, 2012]. Steel slag aggregate generally exhibit a propensity to expand because of the presence of free line and magnesium oxides hence steel slag aggregates are not used in concrete making. Proper weathering treatment of steel slag has reported to reduce the expansion of the concrete.

1.2 Blast furnace slag and steel furnace slag applications

Blast furnace slag (BFS) and steel furnace slag (SFS) have a long history of use as industrial by-products, going back almost 100 years in the United States and 150 years in Europe. Ground granulated blast furnace slag (GGBS) has been used in composite cements and as a cementitious component of concrete for many years. The first industrial commercial use (about 1859) was the production of bricks using unground granulated blast furnace slag (GBS). In the second half of the 19th century, its cementitious properties were discovered, and by the end of 19th century, the first cements containing GBS were produced. Since the late 1950s, the use of GGBS as a separately ground material added at the concrete mixer together with Portland cement has gained acceptance. In some countries, the term 'slag cement' is used for pure GGBS

Both BFS and SFS have unique physical and chemical properties that make them particularly well suited to a variety of uses in construction and civil engineering projects [Huang Yi, GuopingXu, HuigaoCheng, 2012]. The properties of iron and steel slags can vary greatly, depending on the processing done once the slag is removed from the furnace.

Air-cooled BFS produces a durable aggregate that performs well in unbound applications as well as in Portland cement and asphalt concretes. Cooling the slag with water produces a lightweight aggregate for use in masonry blocks and lightweight concrete. Pelletized and granulated BFS can be ground and used to make slag cement. Compared to regular Portland cement, slag cement provides reduced heat of hydration and improved resistance to sulphate attack and alkali-silica reaction. It is also resistant to chloride penetration, sulphate and thaumasite sulphate attack. It has low risk of thermal cracking and a high electrolytic resistance. (Liu chunlin, zhakunpeng, ICAE 2011)

Steel furnace slag typically forms a very angular, durable aggregate that makes it good for use in the transportation industry. SFS has been used successfully in the friction course of hot mix asphalt pavements, as well as in superpave mix designs and stone matrix asphalt. It is also used as a cost effective and environmentally sound feed stock material for the production of Portland cement.Steel slag is a kind of solid waste from the steel production. It makes up a proportion of approximately 15% by mass of the steel output .In China, about 80 million tons of steel slag is discharged every year. Most of the steel slag is disposed of in rubbish dumps,

1.3 The Main Applications of BFS and SFS

BFS (air-cooled):

Uncrushed: fill and embankments (particularly areas subject to severe loading, such as mainline rail systems), working platforms on difficult sites pavements, where binding fines are produced by rolling to break the slag down to fill the voids

Graded road base: on its own or blended with other slags and/or with other natural rocks and sands Crushed and graded: for concrete aggregates, concrete sand, glass insulation wool, filter medium, and use under concrete slabs as a platform.

GBS (granulated BFS) and GGBS:

Cement: the principal use is as cement replacement (when ground, GGBS), replacing 30–50% of Portland Cement in 'normal' concrete, but can replace up to 70% in specialist applications such as marine concrete. GGBS is probably the most applicable product in the cement industry. For slag cement production, GBS can be ground separately or together with Portland cement clinker and calcium sulphate [Huang Yi, GuopingXu, HuigaoCheng, 2012]. Usually, GGBS is ground to a fineness exceeding that of ordinary Portland cement to obtain an increased early strength.

Aggregate: unground GBS is suitable as a normal weight aggregate in concrete.

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Road making: unground GBS can be used as a base layer material in road construction.

Fill material:

Because of its sand-like texture, it is easy to work. Its self-cementing properties cause it to set up over time.

Sub-base:

GBS compacts more readily than rock slag (air-cooled BFS). Initially, the compacted surface of this material is soft, but it hardens with time. Granulated blast furnace slag can have up to 99.5% reactive glassy material, which accounts for its self-cementing properties.

Stabilizing binder:

One of the major benefits of using slag products in a stabilized pavement is the slow rate of the cementation process. The pavement material can be reworked up to two days or more after initial mixing depending on the binder, without reducing the final strength. The performance of both GBS and GGBS in stabilization depends on the degree of fineness of the material, which in turn is a matter of economics. The cost of producing a finer grade of both GBS and GGBS, coupled with the reduced amount of slag stabilizing binder needed to provide equivalent strength, must be balanced against haulage costs. Blends using slag, fly ash and lime have working times up to four times that of GP cement with working times of up to 48 hours being available with some soils.(Ramzitaha, Nasser al-nuaimi)

Other uses include glass making, concrete block manufacture, sporting field sub-base (for drainage), filtration medium, reinforced earth embankments, and mine backfilling and grit-blasting medium requiring fine etching.

BOS (basic oxygen steel slag):

Blending with many other products such as granulated slag, fly ash and lime to form pavement material Other uses include skid-resistant asphalt aggregate, rail ballast asphaltic concrete aggregate, soil conditioner, hard stand areas and unconfined construction fill.

EAF (electric arc furnace slag):

Blending with many other products, such as granulated slag, fly ash and lime, to form pavement material, skid-resistant asphalt aggregate and unconfined construction fill. SFS is most commonly used for asphalt application, as it has better strength, abrasion and impact resistance than BFS, making it particularly suitable for use in areas subjected to heavy vehicle loads and high shear. (Huang Yi, GuopingXu, HuigaoCheng, 2012)

As silicate liming materials, SFS and BFS contain elements with useful properties for plant nutrition and soil quality. The basicity of the calcium and magnesium compounds in the slags improves soil pH. Both elements also serve as plant nutrients and stabilisers for soil aggregates. Magnesium in slags (especially in BFS) has a better solubility than that of magnesium carbonate in limestone and dolomite. Silicate has beneficial effects on plant health, phosphate avail-ability and soil structure. The content of trace elements, such as manganese, copper, zinc, boron or cobalt, satisfies both plant and animal demands.

Iron and steel making slag manufacturing processes and the applications are summarized Common nomenclature Manufacturing process Applications

In 2004, about 23% of BFS was processed as air-cooled slag and 77% as vitrified slag (granulated or pelletized). Most European countries produce both air-cooled and GBFS. In some countries (Belgium, Italy, The Netherlands) only GBFS is produced, while in Sweden and Spain the main product is air-cooled slag. The dominant application is the production of slag aggregates or slag mixtures for unbound or self-binding layers: these accounts for about 64% of generated BFS, most of them granulated or pelletised. About 33% of generated BFS, mainly air-cooled BFS, is used for road construction. Due to their porosity, BFS aggregates are today only used for asphalt road bases and sub-bases, but not for surface layers. Other applications of BFS include interim storage (1.5%),

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internal recycling (0.4%), hydraulic engineering (0.3%) and fertiliser (0.2%).

SFS produced in 2004 was as BOF slags (~62%), EAF slags (29%) and secondary metallurgical slags (~9%). The use rate of SFS is lower than BFS: approximately 11% of the steel slags produced in Europe today are still being dumped. The main areas of SFS application are in the production of aggregates for road construction (45%; asphalt layers, in-situ treatment of unsuitable soils for road construction). Other applications include: interim storage (17%), internal recycling (14%), the production of fertiliser (3%) and hydraulic engineering (3%). Only 1% is used for cement production.

Both the chemical and physical characteristics of BSF and SFS are quality controlled as a result of voluntary operations and treatment both before and during slag production. Quality control is maintained by controlling the characteristics of raw materials, the use of chemical additions (e.g. aluminates in the furnace), cooling rates, etc. to fulfil the requirements of nationally and internationally recognised technical and environmental specifications and standards.

Recently, most of the national standards relevant to slag use have been harmonized. In the European cement standard EN 197-1, nine cements containing between 6 wt. % and 95 wt. % slag are listed. It also contains requirements for glass content and basicity of GBS. The oxide composition of GBS may be used as a guide to possible reactivity. However, investigations have shown that the evaluation of GBS based only on the chemistry or any other single parameter does not give entirely reliable results [1]. The interaction of the slag with Portland cement clinker, calcium sulphates and other materials, as appropriate, has to be considered.

In Europe, severe legal limitations have been put on the Cr (VI) content in cement. Under the EU Directive 2003/53/CE, hydrated cement must not contain more than 2 ppm of soluble Cr (VI) in the dry cement mass. Hence, BOF slag now cannot be used as a raw material, as 10% of the total Cr injected in the kiln is Cr (VI) [11]. However, for BFS slags, Cr (VI) content is not an issue. As shown in Section 3, the concentration of Cr in BFS slags is thousands of times lower than in BOF slags, and Cr leaching is 2–3 orders of magnitude lower.(B. Das, S.Prakash, P.S.R. Reddy, V.N. Misra, 2007)

For each intended field of application, slag must meet the same standards of health and environmental protection as those applicable to primary raw materials and products. In this regard, some slag products are superior to their natural equivalents.

The chemical composition of steel slag is a complex matrixstructure consisting primarily of simple oxides determinedfrom elementary analysis of x-ray fluorescence. According toEmery, steel slag usually contains four major oxides, namely lime, magnesia, silica, and alumina. Minor elements include sulfur, iron, manganese, alkalis and trace amount ofseveral others. Table I shows the list of various ranges of compounds presents in steel slag as reported by Emery The chemical composition of steel slag varied with the steelmaking practice and the quality of steel being produced. However, in accordance with the description from FHWA there were many grades of steel that can be produced, and the properties of the steel slag can change significantly with each grade. Grades of steel can be classified as high medium, and low, depending on the carbon content of the steel. High-grade steels had high carbon content. To reduce the amount of carbon in the steel, greater oxygen levels were required in the steel-making process According to The Federal Highway Administration (FHWA) the processed steel slag has favorable mechanical properties for use as aggregates in construction these include good abrasion resistance, good soundness characteristics, and high bearing strength. These properties greatly improve the performance of asphalt mixes and roadsafety level. SSA exhibits less susceptibility to abrasion due toits high particle density, allowing it to provide better skid resistance than the natural aggregate. Steel slag has

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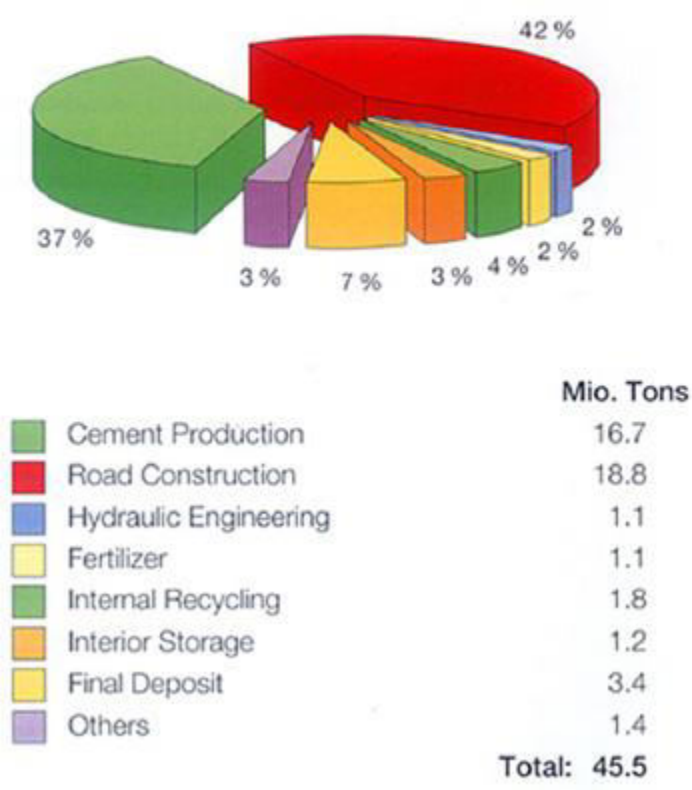
a high degree of internal friction and high shear strength. FHWA Has documented the general mechanical properties ofsteel slag Many researchers have investigated the use of steel slag inasphalt concrete. The previous studies have been conductedon HMA with the varied percentage of SSA. Most of thestudies were concerned with the utilization of steel slag in HMA as a coarse aggregate replacement. The effects of steel slag on the performance of asphalt Concrete are reviewed below. Climate and material variations, the use of steel slag in HMAmust be investigated using local materials, based on localspecifications. Therefore, the aim of this study is toinvestigate the effects of steel slag in HMA specifically for Sudan local materials and climate.



One of the potential barriers to the use of gasification residues is that of legislation. Gasification residues may be classified as waste, and further subdivided, depending whether they are seen to be hazardous or non-hazardous. In this section, relevant Australian federal and state legislation is presented and compared with international legislation.

Although gasification is a mature technology in the chemical industry, its application to power generation is relatively new. No legislation relating specifically to this use appears to have been formulated. Regulations that may be applicable have been developed for coal combustion products (CCPs), which include fly ash, bottom ash, and boiler slag. Regulations on slag disposal or use usually refer to steelmaking slags. As gasification by-products consist of both fly ash and slag, it is most likely that, in the first instance, they would be addressed using existing legislation dealing with CCPs and steelmaking slags. (Dirk Durinck, Fredrik Engstromb, 2008)

Information on legislation relevant to use and disposal of ash has been previously reviewed within the Cooperative Research Centre for Coal in Sustainable Development (CCSD) research program [1–4]. In many countries, ash from coal-fired stations is defined as a waste. The major portion of the ash is discarded in landfill, or in specially constructed ash dams. Following this approach – from an industry viewpoint – coal gasification slags are also likely to fall into the category of 'waste' rather than being seen as a 'product'.

While gasification slags are expected to be more stable than 'conventional' fly-ash, the major concern likely to arise from the disposal and use of IGCC by-products is the potential leaching of environmentally hazardous trace elements. Relevant laboratory leaching procedures and other chemical characterization tests are discussed in Section 3 of this review. This section gives an overview of relevant aspects of waste classification and management regulations, with a particular focus on Australian legislation.

2.Materials and Experiments

In this paper, materials used include ordinary portland cements (OPC), fine aggregate, natural coarse aggregate, silica fume (SF), and steel slag. Fine aggregate is river sand having fineness modulus of 2.62. The chemical and physical properties of OPC cement were quantified by XRD

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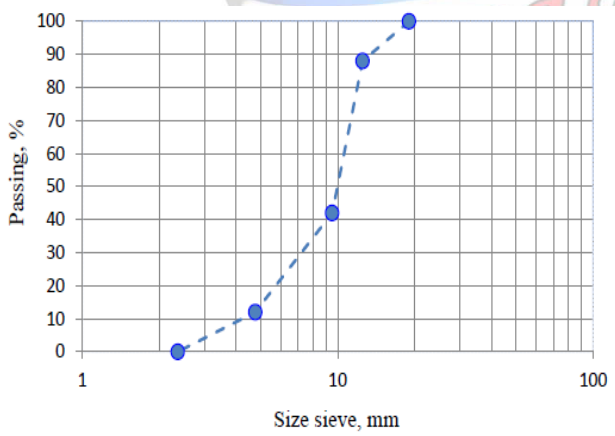
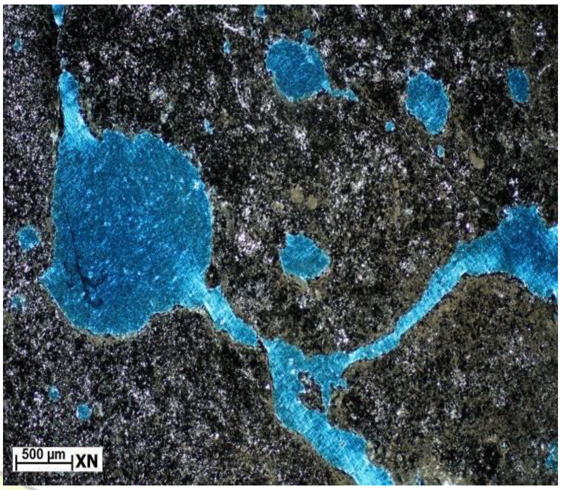
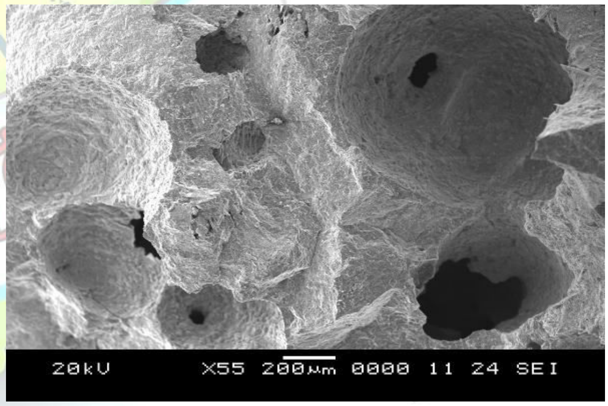
and XRF analysis and shown in Table 1. Natural coarse aggregate, which satisfies ASTM C33-84, is altered basalt and belong to extrusive igneous rock with a maximum size of 20mm. The steel slag, which has large sizes, was ground into various smaller sizes. Because of free lime included in the steel slag, to make the lime stabilized, after grinding, the steel slag was exposed to atmosphere with water spray for one month, and then the steel slag was sieved into separated sizes and combined various sizes together to generate the best grading as shown in Figure 1, with a maximum size of 20mm. The petrography characteristic of the natural coarse aggregate and the steel slag aggregate were evaluated by ASTM C295. The petrography analysis showed that the steel slag aggregate consists of opaque minerals (49.3%) and clay minerals (12.3%). The opaque minerals with very fine-grained are magnetite and iron oxides, which were scattered in the aggregate. In the steel aggregate, the pore shape is circular and slit-shaped pores with interconnectivity, as shown in blue color in Figure 2. The pore diameter is commonly from 0.1mm to 1.0mm. Moreover, the chemical composition of the steel slag coarse aggregate



Grading Of the Steel Slag Coarse Aggregate



The shape and interconnectivity of pores in the steel slag coarse aggregate



The shape and interconnectivity of pores in the steel slag coarse aggregate

To make comparison of concretes using basalt coarse aggregate and steel slag coarse aggregate, the steel slag coarse aggregate is compared to the basalt aggregate in terms of dry density, water absorption, compressive in cylinder, abrasion loss, wet dynamic crushing and sulphate soundness. These properties of both the basalt aggregate and the steel slag aggregate , it can be seen that the steel slag aggregate is much heavier than basalt aggregate due to high content of ferric

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oxides in its composition. Also, with interconnected pores, the steel slag aggregate has higher water absorption, higher cylinder crushing value and higher wetting dynamic crushing value than that of the basalt aggregate. Whereas, the abrasion loss of the steel slag is higher when compared to the basalt aggregate, the ferric oxide which has good friction resistance may contribute to good abrasion loss of the steel slag.

3. EXPERIMENTAL INVESTIGATION

3.1 General

This chapter discusses about the materials and its properties to be used in concrete.

3.2 Materials

3.2.1 Cement

The type of cement is used in the study was ordinary Portland cement 43 Grade the type of cement is desired the strength of concrete, and its compound composition of cement affects the rate of hydration. The strength at every age can be considerably influenced by the cement used. The relative proportions the oxide compositions are responsible to influencing the various properties of cement. Ordinary Portland cement, 43 grade conforming to IS: 12269 – 1987. Some of the properties are tested and listed below.

Table4. 1 physical properties of cement

Sl. No	Property	Value
1	Specific gravity	3.15
2	Standard consistency	29 %
3	Initial setting time	110 min
4	Final setting time	400 min

3.2.2. Fine Aggregate

Locally available sand passing through 4.75 mm has to be used in this experimental work. The following properties of fine aggregates are determined as per IS: 2386-1963.

Table 3.2 physical properties of sand

Sl. No	Property	Value
1	Specific gravity of sand	2.57
2	Fineness modulus of sand	2.80
3	Water absorption	1.57%
4	Bulk density of sand	1710kg/m^3

3.2.3. Coarse Aggregate

The coarse aggregate passing through 20 mm and retaining 4.75 mm has to be used for experimental work. The following properties of coarse aggregate are determined as per IS: 2386-1963.

Table 3.3 physical properties of coarse aggregate

Sl.No	Property	Value
1	Specific gravity of coarse aggregate	2.75
2	Fineness modulus of coarse aggregate	7.16
3	Water absorption	1 %
4	Bulk density of coarse aggregate	1472kg/m^3
5	Impact value	19 %

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3.2.4. Steel Slag

Steel slag is residue of steel industry; it's produced during the separation of molten steel from impurities in steel making furnaces. Steel slag is produced in general two types (1) basic oxygen furnace, (2) electric arc furnace as a byproduct of the production of steel. For this study the steel slag has collected from PULLKIT steel industry at Aeripakkam. The collected steel slag is in the standard size range of 20mm – 30mm. crushing has performed for the steel slag to obtain the standard coarse aggregate zone.

Table 3.4 physical properties of steel slag

Si. No	Property	Value
1	Specific gravity of steel slag	3.9
2	Water absorption	3.6
3	Bulk density of steel slag	1520kg/m^3
4	Zone	II
5	Los Angeles Abrasion	28 %
6	Impact value	29 %
7	Crushing strength	26 %

3.2.5 Water

Clean potable water is used for Mixing and Curing operation for the work. The Water supplied in the campus is of the potable standard of PH value 7 is used.

3.2.6. Chemical Admixture

To improve the workability of fresh concrete sulphonated naphthalene based super plasticizer i.e., Conplast SP 430 was used supplied by WELCOME chemicals, 1.4% (max 2%) dosages was used to increase the workability of concrete. In order to obtain suitable workability, super plasticizer will be added. Steel has angular shape which influences the workability of concrete.

3.5 Mix Proportions per m^3 for M30 of Concrete

S.NO	INGREDIENTS	QUANTITY KG/M^3
1	Cement	350
2	Fine Aggregate	750
3	Coarse Aggregate	1205
4	Water	158
5	SP	2.45

3.3 Methodology

1. Compression strength test, split tensile strength and flexural strength test will be carried out by Indian standards.
2. Sulphate resistance test
3. Water absorption test will be done as per ASTMC 642-81.

Concrete specimens will be prepared with natural coarse aggregate and steel slag coarse aggregate. The mixture will be prepared with the cement of 350kg/m^3 and water to cement ratio of 0.45. The mix proportion of materials 1: 2.14: 3.44 as per IS 10262-2009.

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3.3.1 Details about the specimen

1. For compressive strength the cube size 100×100×100mm. (7, 14, 28 days)
2. For split tensile strength the cylinder size 100mm×200mm. (7, 14, 28 days)
3. For flexural strength the prism size are 100mm×100mm×500mm. (7, 14, 28 days)
4. Durability tests for sulphate test and water absorption test (56 days)

Table 3.5 Replacement level of steel slag in concrete

Coarse aggregate	Steel slag aggregate	Cube in Nos	Beam in Nos	Cylinder in Nos
100%	0%	24	3	3
75%	25%	24	3	3
50%	50%	24	3	3
25%	75%	24	3	3
0%	100%	24	3	3
Total	**specimens**	**120**	**15**	**15**

3.3.2 Testing of specimen

Compressive strength test

For each set three standard cubes are to be casted to determine 7 days, 14 days, 28 days compressive strength after curing. The size of the cube is as per the IS 10086 – 1982.

Compressive strength = load / area N/mm^2

Split tensile strength test

To determine the split tensile strength the cylinders are to be casted. The size of the cylinder is 100mm×200mm of length. Combination of test results is compared with control concrete specimens.

Flexural strength test

The flexural test is to be carried out in beam specimen; the prism sizes are 100mm×100mm×500mm. The test will be conducted on (7, 14, 28 days) as per IS 516 -1959.

Sulphate resistance test

Concrete cubes of size 100mm after 28 days of curing will be dried and weighed. Then cubes will be immersed in 5% sodium sulphate solution for 30 days. Observations will be made after taking the concrete cubes from sodium sulphate solution and cleaning it in fresh water. After drying the cubes the change in weight and also the compressive strength of cubes will be found. The concrete cubes will be deteriorated mainly at edges and will be appeared whitish.

Water absorption test

Procedure as per ASTM C642-81

After 28 days curing the specimens are to be taken out from curing tank. Specimens are dried in an oven at 105^{0}C for 4 hours. The dry specimens are cooled to room temperature (25^{o}C) weighed accurately and noted as dry weight. Dry specimens are to be immersed in a water container. Weight of the specimen at pre-determined intervals to be taken after wiping the surface with dry cloth. This process is to be continued not less than 48 hours or up to constant weight are to be obtained in two successive observations.

$$\% \text{ absorption} = \frac{\text{saturated weight} - \text{dry weight} \times 100}{\text{Dry weight}}$$

4. CONCLUSION

Steel slag is an industrial by-product of steel industry. It possesses the problem of disposal as waste and is of environmental concern. The demand for aggregate in

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construction industry is increasing rapidly and so is the demand for concrete. Thus it is becoming more important to seek suitable alternatives for aggregates in the future. In this study, the natural coarse aggregates (NCA) were replaced with steel slag aggregate (SSA) at various proportions of 25%, 50%, 75%, and 100%. Experiments were conducted to determine the compressive strength, flexural strength and split tensile strength of concrete with various percentages of steel slag aggregate. The results were compared with conventional concrete. The results of this research were encouraging, since they show that using steel slag as coarse aggregates in concrete has no effects on the hardened concrete and also in later ages 56 days, it shows a better performance in strength and durability than natural aggregate.

The physical properties of SSA basically satisfy the requirements of Marshall Specification for the design of HMA. Based on laboratory test results, SSA appears to be especially beneficial for the use in Sudan to reduce the dependent on naturally occurring aggregate. Thus, it is recommended that the producers and the users of AHM in Sudan consider the use of SSA.From the economic point of view, utilization of steel slag as road construction aggregate may reduce the cost of extracting and processing naturally occurring aggregates. The steel producing industry may also reduce their cost of treating and disposing the huge number of steel slagstockpiles.The use of natural aggregate in the HMA layer of road pavement is seen as a wasteful use of a finite natural resource. Therefore, the use of waste (secondary) materials is recognized as being of benefit to both environment and society. Of the various waste materials, the steel slag can be considered reasonable alternative sources of aggregate for concrete asphalt mixture productions. Further research is still required to obtain new specifications, for the use of SSA in different fields of application to conserve.

The results of the study can be summarized as follows:

1. As there was a belief that the steel slag aggregates have expansive characteristics because of high percentage of calcium and magnesium oxide in its chemical composition. But in the present steel slag chemical composition, these elements are lesser in amount and hence the expansion of concrete will not takes place during hydration process.

2.Slag aggregate having acceptable properties such as crushing value, impact

FURTHER STUDY

1. 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.
2. Further investigation on resistance of concrete with steel slag aggregates to attack by alkali silica reactions, carbonation; sea water attack, harmful chemicals and resistance to high temperatures are needed.
3. The behavior of steel slag aggregate concrete under corrosive environments and its fire resistance capacity also should be investigated.
4. Due to presence of several dangerous heavy metals and salts in the steel slag aggregate, leaching tests should be carried out to verify its environmental compatibility.
5. A much more extensive field study on a concrete structure made with steel slag fine aggregates used in the mixture should be conducted and changes in durability and mechanical properties should be investigated and correlated to laboratory results.

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6. In general can be said that the use of steel slag especially at optimal ratio improved the sub base layer density, strength and failure resistance especially for horizontal distance of 60 cm from load center. Thus, this 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.
7. Additional work is necessary to establish long-term performance, especially concerning what is reported in the literature about the expansive characteristics of steel slag aggregates when used in concrete
8. Characterization of slag available from various steel manufacturing plants could be done for the compare-son of performances of concretes obtained with these slag.
9. Collection of data for characterization of such slag wastes generated from all the steel making plants is of extreme importance & could be taken up immediately.
10. Study of environmental problems created by such wastes remaining without recycling and proper utilization.
11. Development of mathematical model based on various parameters to ascertain its strength characteristics in respect of concrete.
12. The influence of slag particle size on carbonation has been verified. Although depending on the end-use, the largest particle size fraction of the available slag is recommended for outdoor use because the actions of the environmental factors that enhance lixiviation are tempered.
13. The accelerated ageing procedure based on percolating a previously carbonated water solution through the slag column complements a batch leaching test. It allows the gradual leaching of
14. Analyses with simulated acid rain and provides information about the gradual and total chemical emission from the slag.
15. The joint use of the accelerated carbonation method and the percolation test is proposed as a useful tool for environmental risk assessment concerning the long-term air exposure of EAF black slag.

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