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Technical Feasibility of Sustainable Steel Slag Mixed Concrete

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Abstract*: Introduction of new eco-friendly construction materials like steel slag is being necessary and promoted where exploration of natural aggregates for construction is restricted due to environment cause. Ecology gets threatened by disposal issue of steel industry waste products (Steel slag). This study focused on the properties of steel slag and its technical suitability in a concrete as replacement to coarse aggregates. Effects on workability, mechanical and durability properties were studied. Steel slag mixed concrete found suitable in mechanical properties, when in increase in percentage of replacement to coarse aggregates is high, whereas workability acted adversely. Optimum replacement (30 to 75 percentages) observed maximum results. Surface characteristics were affecting on workability and durability properties intensively. Steel slag aggregates found stable against acid attack, permeability, expansion, abrasion and temperature. This study culminates that the steel slag mixed concrete improves the properties of concrete than controlled concrete. Utilization of steel slag mixed concrete leads to sustainable and cost effective development.

***Index Terms*: Durability, Properties of concrete, Steel slag, Sustainable.**

I. INTRODUCTION

Concrete is major construction material used in construction projects irrespective of scale of projects. Projects of highway construction, buildings, industry, aviation and hydraulic construction etc. are using extensive quantity of concrete. Demand of ingredients in large quantity is increased to meet the concrete production. Concrete is a wet matrix of cement, coarse aggregates, fine aggregates and additives. Concrete properties are the reflection of ingredient's properties and methodology [1], [2]. Coarse aggregate accommodate 70 percentage of volume in concrete. Limited natural resources are available of aggregate in India. Government is imposing restrictions on explorations of natural aggregates due to it is threatening the effect on environment. Use of artificial industrial slag instead of natural aggregate can defeat environment and produce sustainable concrete [3]. Use of Steel slag in concrete is noted suitability in regards to strength, durability of concrete; steel slag with water absorption should not more than 10 percentages and less than 0.5 percentage of sulphate as SO_3. [4] .

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An attempt to define steel slag as per ASTM was made by [5], "a nonmetallic by-product from steel industry which is developed in basic oxygen, electric arc or open hearth furnace method of steel production; consisting calcium silicate and ferrites in combination of diffused oxides of iron, manganese, calcium and magnesium"

Steel slag used in many research in different aspects, domestic slag contents significantly 25-30 percentage of Calcium Oxide (CaO) which is pozzolanic in nature. The percentage of CaO can be used as portion of binder or as sbinder. Steel slag satisfactory proved the improvement in bearing capacity when used as cement bound base coarse [6].

II. SLAG AS A CONSTRUCTION MATERIAL

Steel slag is a by-product in steel industry which produced by following processes;

1. Basic Oxygen Steel (BOS): exothermic reaction between molten pig iron and oxygen blown into steel making vessel which produces large quantity of steel slag
2. Electric Arc Furnace (EAF): high voltage current is used to melt the steel scrap and produce lea quantity steel slag. [7]

Fig. 1 Steel slag dumping yard in steel industry

Properties of steel slag are affecting on concrete properties, iron and steel slag are containing Silica (SiO_2), Calcic (CaO), Alumina (Al_2O_3) and magnesia (MgO) as a principal constituents up to 95 percentage of volume [5]. Steel slag production involved two procedures; water cooling and air cooling, these process are affecting on the chemical

Chemical elements	Water cooled process In Percentage	Air cooled process In Percentage
CaO	33.22	38.48
Fe_2O_3	29.64	24.20
SiO_2	10.86	11.01
MgO	13.09	10.22
Al_2O_3	1.66	8.67
MnO	6.18	5.47
Na_2o	0.02	0.07
K_2O	0.06	0.04

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composition of steel slag which is depending upon the availability of oxygen for reaction. Chemical analysis of steel slag as shown in table 1 [8].

Table 1 Chemical composition of steel slag

Fig. 2 sorted steel slag to utilize in concrete as coarse aggregates

Coarse aggregate was partially and fully replaced by steel slag was collected from ISMT, Steel Manufacturing Unit, Pune (India). Aggregates used for production of concrete were possessed following physical properties in table 2. Physical properties of steel slag aggregates are quite similar when compared with natural aggregates [3].

Table 2 Properties of aggregates

Sr. No.	Property	Coarse Aggregate	Steel Slag	Remark
1	Specific Gravity	2.67	2.61	
2	Water Absorption	1.2%	1.14 %	
3	Silt Content	-	-	
4	Sieve Analysis	FM= 4.39	FM= 4.98	
5	Impact Value	7.89%	16.93 %	Should not Exceed 30%
6	Abrasion: Los Angeles	23.43%	25.86 %	Maximum permissible; 30%

Fully replacement of coarse aggregate by steel slag was not found yield better strength in any mechanical properties of concrete, 60 percentage of steel slag aggregates replacement was effective than 100 percentages which possessed slightly bleeding and segregation. [9], [10]. No major difficulties are found in concrete when steel slag used instead of course aggregate below 75 percentage [11]. Steel slag could be used in concrete in replacement of fine and coarse aggregates up to 40 percentages and 30 percentages respectively; optimally; in consideration of compressive strength only [12]. This study [13] suggested avoiding the use of steel slag as coarse aggregate and fine aggregate at a time which was showing adverse effect on workability.

Steel slag are acting as inert in nature when used in concrete, strong, durable, good interlocking properties, good against abrasion does not generate alkali- aggregate reaction. Use of steel slag is the recovery by-product which reduces mining and save ecology [14], [15].

III. EFFECTS OF STEEL SLAG

A. Effects on fresh concrete

Steel slag added in high performance concrete, showed decrease in slump as decrease in the aging period of steel slag aggregates. Surface hardness and roughness of aggregates increased as per their age; due to environmental impact on steel slag aggregates [16]. Greater percentage of steel slag aggregates available in concrete observed lower slump value. If steel slag used a replacement of sand; slump value decreased too due to existing of non-finer grain of steel slag [17]. Increase in high density steel slag percentage in concrete noted decrease in slump and tending to segregation. Improved workability observed when steel slag aggregates added in combination of silica fumes, finer & rounded particles of silica fumes extended workability up to 12 percentages without adding super-plasticizer [18].

Unit weight of fresh concrete increased as percentage of steel slag increased which is attributed to high specific gravity of steel slag aggregates [18]. An actual unit weight measured was slightly higher in every stage of inclusion of steel slag than designed unit weight as shown in fig. 3. Unit weight indicates the consistency in operations of concreting, uniformity of mix and changes in the mixture [11].

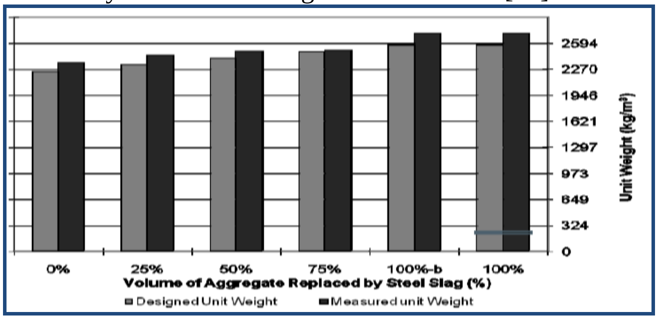

Fig 3 Unit weight of aggregates replaced by steel slag

Air content and temperature of concrete in steel slag mixed and natural aggregate mixed concrete showed nearer values which did not noted significant variations; case which showing the steel slag is acting inert as like natural aggregates. Fig. 4 and fig. 5 are showing the air content and temperature variation in different steel slag added mixes [19] where;

CC- 0 percentage addition of steel slag as fine aggregates,
CFP1- 10 percentage addition of steel slag as fine aggregates,
CFP2- 20 percentage addition of steel slag as fine aggregates,
CFP3- 30 percentage addition of steel slag as fine aggregates,
CFP4- 40 percentage addition of steel slag as fine aggregates.
CFP5- 50 percentage addition of steel slag as fine aggregates.

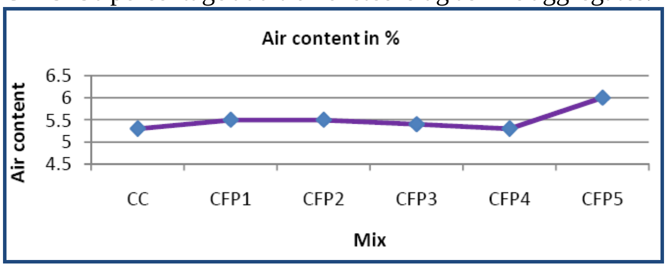

Fig. 4 Air content and steel slag aggregate mixed concrete

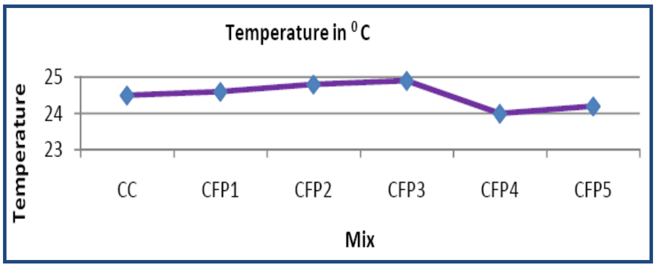

Fig. 5 temperature and steel slag aggregate mixed concrete

Workability of steel slag added concrete is lying in moderate when it used up to 30 percentage and 40 percentages replacement to fine and coarse aggregates. Workability is a function of size and shape of aggregates, gradation of aggregates, texture and surface characteristics of aggregates, water absorption capacity; optimum water cement ratio etc. loss in workability is due to the fineness of fine aggregates and surface characteristics of coarse aggregates which can be observed in fig. 2 (steel slag as construction material).

B. Effect on mechanical properties

Extensive literature is available to correlate the percentage of steel slag used in concrete and mechanical properties; this study put some noteworthy study and optimal dosage of steel slag in concrete for maximized mechanical properties. Steel slag was replaced to fine aggregate and coarse aggregate respectively and with combination of other additives, observed mechanical properties for the significant mixture.

Maximum compressive strength is noted at 25 percentages of replacement of fine aggregate by steel slag in concrete [20], this study is limited to 40 percentages of replacement. A remarkable change in compressive, flexural and split tensile strength was observed when 30 percentage fine aggregates were replaced by steel slag aggregates [19]. Compressive strength increased by 1.1 times than the controlled concrete when it was added with steel slag as coarse aggregates. Concrete of any grades (M20, M30, M40 and M50) perceived 4 to 7 percentage increased compressive strength when coarse aggregates replaced by steel slag [10]. Addition of 30 percentage steel slag showed up to 40 percentages and 36.67 percentages improvement in compressive and flexural strength [21]. Use of 75 percentage of steel slag as coarse aggregate showed significantly changes in mechanical as well as acid attack properties, this study also commented that use of waste as a aggregates saves up to 10 percentages of cost of concrete [3]. Mechanical properties of steel slag mixed concrete was showing an less deviations than controlled concrete in which split tensile test showed greater results than other mixed when mixed with 75 percentages of steel slag [22]. Steel slag could be added up to fully replacement of coarse aggregates in combination of water reducing agent for improvement in mechanical properties [11].

Addition of steel slag and rubber tyre as coarse aggregates did not carry any significant effect of mechanical properties of concrete. Dilatometric effect (less shrinkage) was observed in steel slag mixed concrete [23]. Compressive strength of coarse aggregates increased by 4.6 percentages when steel slag replaced to coarse aggregates by 30 percentages and 27.07 percentages when steel slag replaced to fine aggregates by 40 percentages. Fig. 6 is showing a typical nature of mechanical strength against replacement of steel slag [17]. Higher values of compressive, flexural and split tensile strength had been noted at 66.67 percentages of coarse aggregates replaced by steel slag. Maximum values were obtained for all above properties when steel slag added with 20 percentages of silica fumes [18]. Pores present in concrete were filled with the cement gel and silica fume's fine particles and aggregate to gel bonding improved which resulted into mechanical properties of concrete. Compressive strength assessed with age of steel slag aggregates; showed that 30 to 36 months aged steel slag aggregates were quite good in the compressive strength. Flexural strength increased by 46 percentages at 28 days when added steel slag [16]. Deflection increased gradually when test specimen loaded, less deflection noted in deflection test for steel slag mixed concrete [17].

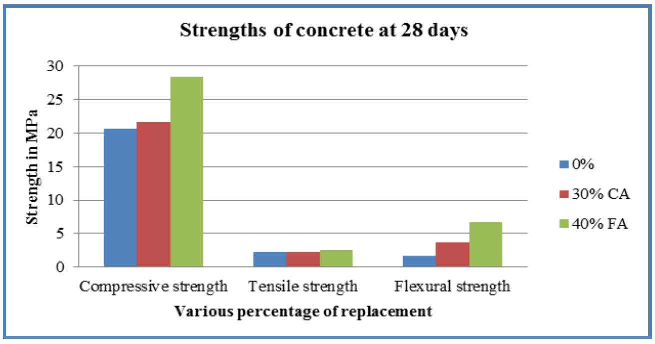

Fig 6 Mechanical properties of steel slag mixed concrete at 28 days

C. Effect on durability

Assessment of steel slag mixed concrete towards the durability is most important parameter to evaluate concrete. Limited literature focused on the results of several test; are discussed below.

Volumetric changes in concrete leads to durability causes and failure of concrete. this study suggested to conduct volumetric swell test before use of steel slag [24]. Steel slag aggregates possess an expansion in most conditions. Experiment resulted in no change in length or slightly changes in length about 0.034% after 120 days in 100 percentages replacement of steel slag in concrete, as shown in table3 [11]. Un-hydrated free lime and magnesium oxides present in steel slag are having potential to expand in hydration reaction when comes in contact with humid environment.Weight loss after acid resistance test was lesser in 30% steel slag coarse aggregates mixed concrete and 40% steel slag fine aggregates. Dehydration rate of steel slag mixed concrete was high in sulphuric acid than hydrochloric acid which resulted into weight loss [17]. Reduction in pores could be achieved by using steel slag as pore filler which resulting fine and discontinuous pore concrete, ultimately increased impermeability [25]. Permeability coefficient of coarse steel slag added concrete reduced up to 50 percentages in compared with controlled concrete.

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Mixes with steel slag replaced to coarse and fine aggregates showed more water permeability [18].

Abrasion coefficient of steel slag mixed concrete is very small, when it tested to ASTM C418; was showing excellent abrasive resistivity [26]. Abrasion resistance increased as increase in the steel slag in high performance concrete and increased with age of concrete; as shown in fig. 7 and fig. 8 [16].

Table 3 Expansion length in concrete specimen

mixture (%)	Specimen ID#	Initial CRD (in.)	CRD 7 Days (in.)	Length Change (%)	CRD 28 Days (in.)	Length Change (%)	CRD 90 Days (in.)	Length Change (%)	CRD 120 Days (in.)	Length Change (%)
Control A	ctrl-A	0.0459	0.0462	0.003	0.0459	0.000	0.0430	-0.029	0.0493	0.034
Control B	ctrl-B	0.0558	0.0561	0.003	0.0556	-0.002	0.0525	-0.033	0.0574	0.016
25%	25-A	0.0000	0.0000	0.0000	0.0000	0.000	0.0900	0.900	0.000	0.000
25%	25-B	0.0208	0.0207	-0.001	0.0186	-0.022	0.0196	-0.013	0.0232	0.024
50%	50-A	0.0045	0.0055	0.01	0.0044	-0.001	0.0041	-0.004	0.0079	0.034
50%	50-B	0.0004	0.0001	-0.003	0.0000	-0.004	0.0009	0.005	0.0027	0.023
75%	75-A	0.0295	0.0285	-0.01	0.0262	-0.033	0.0266	-0.029	0.0315	0.02
75%	75-B	0.0000	0.0000	0.0000	0.0000	0.000	0.0990	0.99	0.000	0.000
100%	100-A	0.0496	0.0320	-0.176	0.0279	-0.217	0.0000	-0.496	0.0355	-0.141
100%	100-B	0.0298	0.0112	-0.186	0.0095	-0.203	0.0000	-0.298	0.0107	-0.191

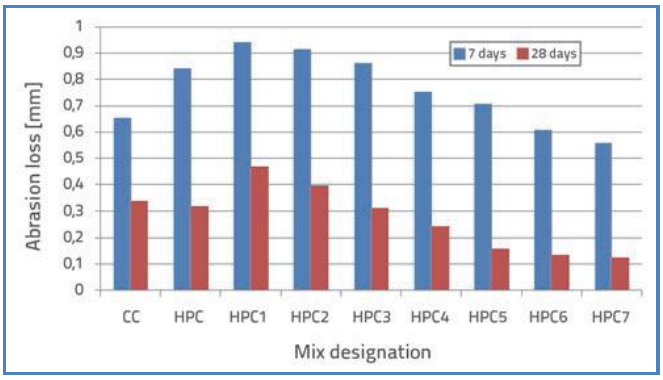

Fig. 7 Steel slag mixed concrete and abrasion

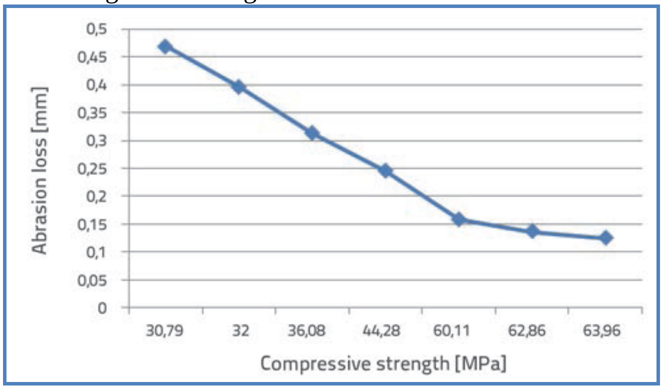

Fig. 8 Compressive strength and abrasion

Permeability of chloride ions has been investigated and assess as per IS 456:2000, moderate and low penetrability against chloride ion showed by concrete mixed with 30 percentages steel slag as coarse aggregates and 40 percentages as fine aggregates respectively [12]. Penetrations of ions are restricted by calcium hydrated gel in secondary hydration of steel slag which makes dense structure of harden cement paste.

Concrete mixes in which steel slag added up to 75 percentage did not shown any change in durability factor, when test was conducted as per ASTM C666 to assess the freeze – thaw resistance. Concrete mixes with 100 percentages steel slag showed the worst reactive dynamic nodule than 64 percentages [11]. High volume of air entrapped in the mixes was reason for failing of specimen in freeze – thaw test. Mechanical properties of steel slag mixed concrete were influenced by temperature, a sharp drop in results were noted when temperature ranges from 6000C to 8000C. This study focus on that steel slag heated up to 10000C prior to use in concrete shows better stability in mechanical properties of concrete [27]. Steel slag aggregates are showing unstable expansion after 5500C in mineralogical and dilatometric analysis when leads to pronounced micro cracking at aggregates-cement interface.

IV. CONCLUSIONS

- Significant improvement in mechanical properties could achieve when inclusion of steel slag from 30 percentages to 75 percentages. Limiting percentages of inclusion of steel slag are adverse reflection of more addition of steel slag on workability.
- Steel slag could be used as fine aggregates limiting to replacement up to 30 percentages only to improve workability of concrete but addition of steel slag as fine and coarse aggregates should avoid.
- To produce high density concrete; steel slag aggregates are an option.
- Concrete mixed with steel slag showed the similar and improved properties against durability significantly; could be preferred as durable concrete ingredient.
- Utilization of steel slag in concrete saves cost up to 10 percentages; and produce sustainable option instead of natural aggregates

V. RECOMMENDATION

Further technical assessment of steel slag mixed concrete is recommended to study alkali-silica reaction, carbonation, environmental attack and surface properties against external forces. Further, Economical assessment is also needed to prove the steel slag as economical material.

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