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Comparison of Properties of Steel Slag and Natural Aggregate for Road Construction

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Abstract **Steel slag is an industrial by-product of steel industry and India is India is the 3rd largest steel producer in the world with total steel production of 95.6 MT per annum. It possesses the problem of disposal and is of environmental concern. The industrial waste has been encouraged in construction industries as a substitute for natural resources for many years such as fly ash. Concrete is used more than any other material in the world so the demand for aggregate in construction industry is increasing rapidly. To find suitable alternatives to natural aggregate is becoming a more challenging task, as nearly three parts of the total volume of concrete contained of natural aggregates only. This paper presents properties of steel slag found out by performing physical, chemical and mechanical test on slag and the results are compared with that of natural aggregate. The results shows that steel slag properties are nearly same as that of natural aggregate which enhances the possibilities of use of steel slag as an alternative to natural aggregate.**

Keywords—Fly Ash, Natural Aggregate, Road Construction, Steel Industry, Steel Slag

I. INTRODUCTION

Waste product obtained from steel industry is called as Steel Slag. It is obtained as a residue, during the manufacturing of steel. Due to high disposal cost as a waste material and its adverse effect on environment most of the developed countries are successfully utilizing the slag as useful construction material[1]. It is successively used as an alternative for natural aggregate for road construction works, for stabilization of soil, and on top layer of flexible pavement. Even thoug still a large quantity of steel slag obtained during manufacturing of steel in steel industries are disposed of in stockpiles resulting a large land area are occupied for the disposal of this useful resource. Lot of research work has done to use of steel slag as an alternative to natural aggregate in asphalt concrete design for construction of road. The best option for management of this waste product is recycling. This will leads not only in saving of landfills reserved for its disposal but also in saving of natural resources thus saving environment.

II. STEEL INDUSTRIES FACT FILE

In the iron and steel industry large amounts of slags are accumulated during the production of iron and steel. A main distinction is drawn between blast furnace slag, steel slag and secondary slag. Blast furnace slag accumulates during the production process of pig iron. Steel slag is obtained by further refining of iron in a basic oxygen furnace(BOF) or from the melting of scrap in an electric arc furnace(EAF). The further processing of steel is classified as secondary steelmaking. One example is the production of stainless steel.

A. Material Streams

A main distinction is drawn between slag from the production of pig iron (blast furnace slag), slags from steel processing (BOF-slag (basic oxygen furnace slag), EAF-slag (electric arc furnace slag)) and secondary slags from secondary steelmaking. The main components of slag are CaO, SiO2, Al2O3, MgO and Fe2O3. Steel Slags chemical composition highly depends not only on the iron or steel production process but also on the additives used. Different additives and different measures (like cooling and further treating of the slag) can influence its quality. With increasing recycling rates of internal wastes (dusts, mill scales and sludges) as well as external wastes (scraps) unwanted accumulations of elements, especially heavy metals (Pb, Zn) occur. The physical characteristics (like vitreous or crystalline structure, particle size) can be influenced via the cooling conditions whereby different uses for the slags arise. In addition to the chemical composition, the elution of hazardous substances is important.

B. Basic Oxygen Furnace Slag

Basic oxygen furnace (BOF) slag arises when steel is produced from pig iron, direct reduced iron or scrap. The amount of slag depends on the amount of silicon in the pig iron, because this is connected with the amount of lime

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added. The BOF is used to produce steel. In steel making the objective of oxygen is to burn (oxidize) the unwanted impurities which the metallic feedstock contains. Thus the main elements converted into oxides are manganese, carbon, silicon, sulphur and phosphorus. Undesirable impurities are removed with the off-gas or the liquid slag. The oxidizing reactions are exothermic thus increasing the temperature of the molten iron. Scrap, iron ore or other coolants are added to cool down the reaction and maintain the temperature. The production of steel by the BOF process is a discontinuous process. During the steelmaking process, slag is formed. Usually the slag is cooled and crushed, after which the metallic iron is recovered by magnetic separation.

C. Electric Arc Furnace Slag

In electric arc furnaces (EAF) direct smelting of iron-containing materials like scrap is usually performed which play an important and increasing role in modernsteel work design. EAF is the major feed stock for ferrous scrap which may compromise scrap from inside the steelworks (e. g. off-cuts), cut-offs from steel product manufactures (eg.vehicle builders) and capital or post consumer scrap (end of life products)[4]. Also, direct reduced iron is used as feedstock. The slag is formed from lime to collect undesirable components in the steel in the BOF. EAF-slag has a lower amount of free CaO than BOF-slag.

D. Waste Material

The two biggest wastes generated in an integrated steel plant are iron slag and steel slag. Removal of 'iron' from iron ores is a very complex process which is not possible without a number of other materials that are added as catalysts or flux[1]. These ingredients forming a matrix are to be periodically cleaned up after steel making. These ingredients forming a matrix removed in bulk is known as steel slag. It consists of silicates and oxides. Basic oxygen process is used to produce steel in modern integrated steel plants. Depending on the size some steel plants use electric arc furnace smelting. In basic oxygen process, dolomite (CaOMgO) and lime (CaO) are used as flux in the furnace. The high pressurized oxygen is injected skillfully lowering the launce and then this oxygen mixed with the impurities of the charge which are finally separated out of the furnace. All the impurities like manganese, silicon, phosphorous, some liquid iron oxides and gases like CO2 and CO combined with lime and dolomite forms steel slag. Finally liquid steel is poured into a ladle and the leftout slag in the vessel is transferred to a separate slag pot. Depending on the different quality of steel, varying quantities of slag known as furnace slag or tap slag, raker slag, synthetic or ladle slag and pit or clean out slag are generated. Fig1 shows the operations required in steel and slag making in modern steel plant[1].

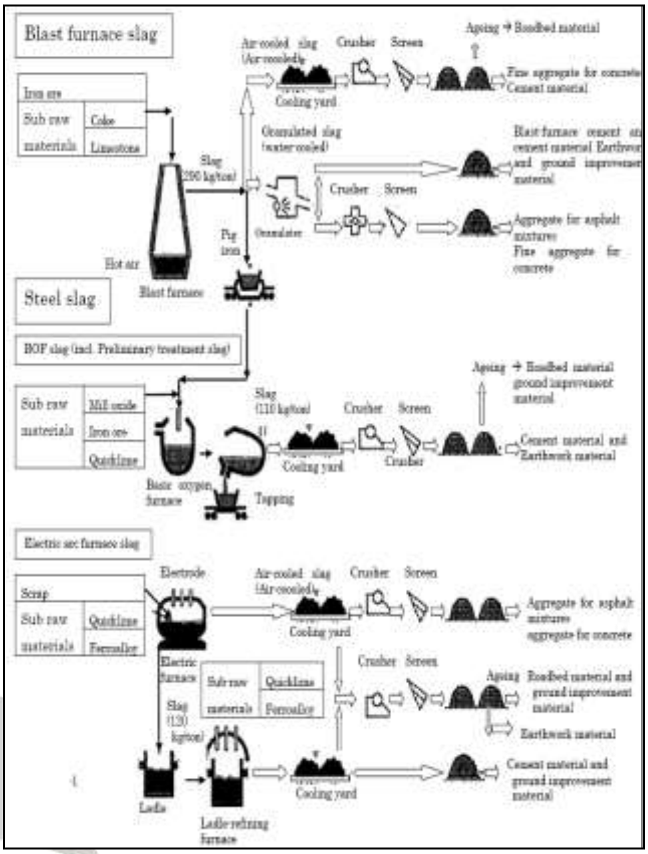

Fig-1 Modern Steel Plant

The steel slag produced during the primary stage of steel making is known as furnace slag or tap slag which is the major share of the total slag produced in the operation. After the first operation, when molten steel is poured into ladle, additional; flux is charged for further refining. This produces some more slag which is combined with any carryover slag from first operation[2]. It helps the in absorbing of de oxidation products, simultaneously providing heat insulation and protection of ladle refractories. Slag produced on this operation is known as raker and ladle slag.

Fig-2 Hoppers crushes the Slag to from +100 mm size upto 60mm size

Fig-3 60 mm size of slag crushes upto 20mm size in 3rd hopper

Fig-4 Metallic Slag Separator

Fig-5 Screens

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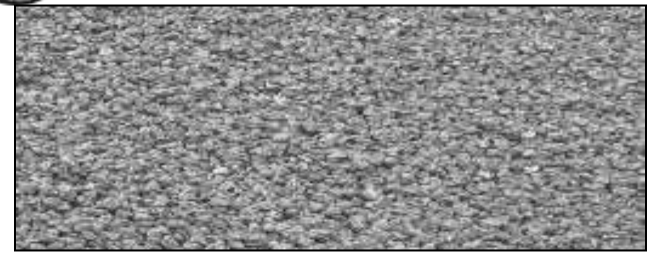

Fig-6 Hip of Steel Slag

The Steel Slag generated are in large size which canaot be used directly also it contains metal in it and hence it is crushed in various hoppers to get the desired size. The steel slag had grayish white color with number of pours on the surface. Fig. 3.2 shows the crushing process of steel slag in local steel industry. Steel slag is expansive in nature hence it must undergo the weathering process before utilizing it as an alternative for natural aggregate in construction. Weathering process is done to reduce the free lime quantity present in the steel slag to acceptable limits. In this process the steel slag stockpiles are made and it is left for a period of at least 4 months in exposed weather condition as shown in Fig. 3.3. During this process the water is sprinkled on the stockpiles of steel slag so that the hydration process between lime and water takes place as the hydration of free lime (CaO) or free magnesia (MgO) is responsible for expansive nature of steel slag.

III. EXPERIMENTAL STUDY

In this part various properties of steel slag like physical, chemical and mechanical are determined as per the methodology given in Indian Standard Codes[5] for aggregates and are compared with the natural stone crushed aggregates. List of I.S. codes available for aggregates are as follows:

IS2386 (Part I) 1963 Particle shape and size

IS2386 (Part II) 1963 Estimation of deleterious materials and organic impurities

IS2386 (Part III) 1963 Specific gravity, density, voids and absorption

IS2386 (Part IV) 1963 Mechanical Properties

IS2386 (Part V) 1963 Soundness

IS2386 (Part VI) 1963 Measuring mortar making properties of fine aggregates

IS2386 (Part VII) 1963 Alkali Aggregate Reactivity

IS2386 (Part VII) 1963 Petrographic Examination

A. Physical Properties

Physical properties such as flakiness and elongation index, specific gravity and moisture content of steel slag and natural aggregate were found out as per respective IRC specifications[56] and tabulated in table. No.1

Table 1. Steel Slag and Aggregate Physical Properties and IRC Specifications

Parameter	IS Code	Steel Slag	Aggregate	As per IRC Specification
Flakiness Index	IS2386 (Part I) 1963	4.48%	12%	Not exceeding 30%
Elongation Index		14.05%	14.50%	No specified limit
Specific Gravity		2.91	2.65	2.5 to 3.0
Water Absorption	IS2386 (Part III) 1963	2.5%	1.02%	0.1 to 2% for road surfacings, upto 4% for base courses, maximum upto 10% for aggregates used in bituminouous surface dressing
Soundness Test	IS2386 (Part V) 1963	11.20%	7.80%	Maximum permissible loss after 5 cycles ≤12% by using Sodium Sulphate

B. Mechanical Properties

Mechanical properties such as Impact value, crushing value and abrasion value of steel slag and natural aggregate were found out as per respective IRC specifications and tabulated in table. No. 2

Table 2. Steel Slag and Aggregate Mechanical Properties and IRC Specifications

Parameter	Steel Slag Property	Aggregate Property	As per IRC Specification
Impact Test (%)	23.21	19	Not exceeding 30% for concrete pavements
Crushing Test (%)	38.55	21	Not exceeding 45%for concrete pavements other than wearing surfaces
Abrasion Value (%)	21.2	19	Not exceeding 30% for concrete pavements

C. Chemical Properties

Chemical composition of steel slag as provided by the industry is mentioned in table. No. 3

Table 3. Chemical Composition EAF Slag

Steel Slag Present study (%)	Steel Slag Present study (%)	Composition provided by NSA (%)
Iron Oxide FeO	1 – 2.5	24
Calcium Oxide Cao	45 – 50	42
Silicon Oxide SiO2	20 – 22	15
Magnesium Oxide MgO	10 – 15	8
Alluminium Oxide Al2O3	4 – 8	1 -5

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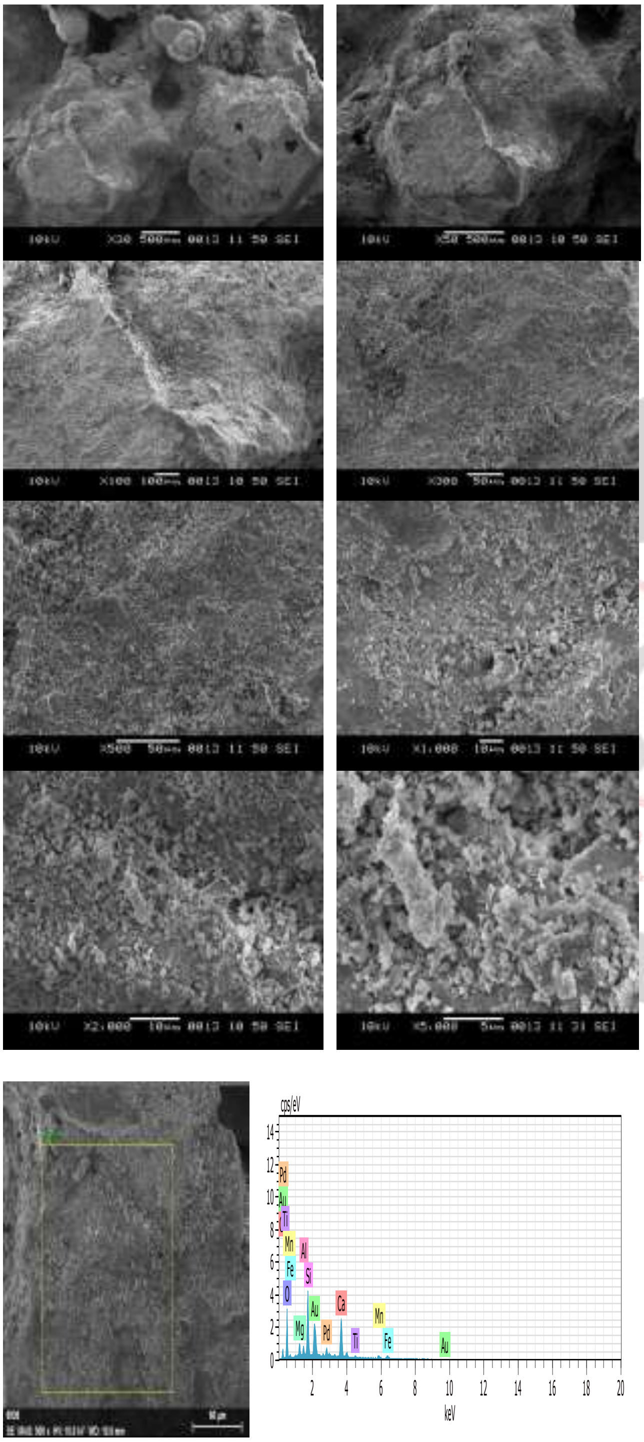
The values of chemical composition of locally available steel industry were provided by Steel Industry where as the values in the next column are typical steel slag chemical compositions provide by National Slag Association (accessed Nov 2003)[6].

D. SEM Analysis of Steel Slag

SEM and XRD test of steel slag were conducted at VNIT are shown in fig. no. 7



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El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
Ca	20	K-series	10.87	26.09	24.19	0.43
Au	79	M-series	6.93	16.63	3.14	0.32
O	8	K-series	6.76	16.21	37.65	1.15
Fe	26	K-series	6.68	16.03	10.67	0.52
Si	14	K-series	5.09	12.22	16.17	0.25
Mn	25	K-series	4.31	10.35	7.00	0.32
Pd	46	L-series	0.90	2.17	0.76	0.08
Mg	12	K-series	0.11	0.26	0.40	0.04
Ti	22	K-series	0.02	0.04	0.03	0.03
Al	13	K-series	0.00	0.00	0.00	0.00
		Total:	41.68	100.00	100.00	

Fig-7 SEM Analysis of Steel Slag

Measurement Conditions: **(Bookmark 1)**

Dataset Name	*Material Steel Slag*

File name C:\Documents and Settings \ mmxrd \ Desktop \ Datta Meghe wardha 1.3.2018\coarse material 1.xrdml
Comment Configuration=Stage Flat Sample, Owner=User-1, Creation date=11/28/2005 4:51:48 PM
Goniometer=PW3050/60 (Theta/Theta); Minimum step size 2Theta:0.001; Minimum step size Omega:0.001
Sample stage=PW3071/xx Bracket
Diffractometer system=XPERT-PRO
Measurement program=powder Scan, Owner=User-1, Creation date=6/12/2006 4:01:29 PM
X Cel

Measurement Date / Time	3/1/2018 11:57:42 AM
Operator	USER
Raw Data Origin	XRD measurement (*.XRDML)
Scan Axis	Gonio
Start Position [°2Th.]	10.0014
End Position [°2Th.]	99.9824
Step Size [°2Th.]	0.0170
Scan Step Time [s]	10.3366
Scan Type	Continuous
PSD Mode	Scanning
PSD Length [°2Th.]	2.12
Offset [°2Th.]	0.0000
Divergence Slit Type	Fixed
Divergence Slit Size [°]	0.4785
Specimen Length [mm]	10.00
Measurement Temperature [°C]	25.00
Anode Material	Cu
K-Alpha1 [Å]	1.54060
Generator Settings	40 mA, 45 kV
Diffractometer Type	0000000083005381
Diffractometer Number	0
Goniometer Radius [mm]	240.00
Dist. Focus-Diverg. Slit [mm]	91.00
Incident Beam Monochromator	No
Spinning	No

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Main Graphics, Analyze View: **(Bookmark 2)**

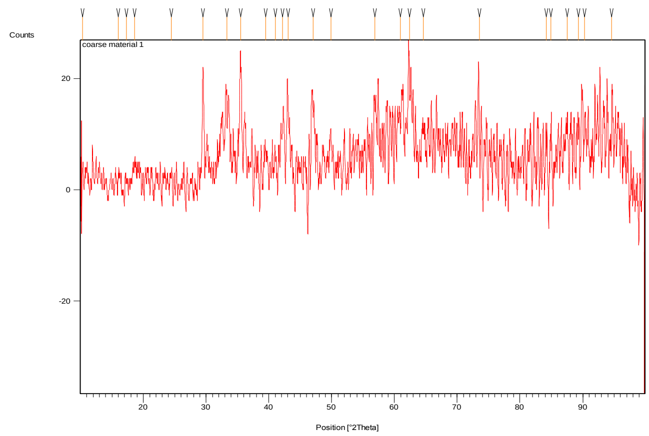

Fig-8 XRD Analysis of Steel Slag

Peak List: (Bookmark 3)

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]
10.3196	3.42	0.4080	8.56518	17.86
15.9694	1.10	0.6528	5.54537	5.72
17.3045	1.59	0.4896	5.12040	8.30
18.5767	3.75	0.8160	4.77251	19.56
24.4416	2.40	0.4896	3.63898	12.52
29.4963	18.54	0.4896	3.02588	96.70
33.3505	8.73	0.8160	2.68446	45.53
35.5035	19.17	0.4080	2.52645	100.00
39.4938	5.77	0.9792	2.27990	30.10
41.0071	5.47	0.4080	2.19919	28.52
42.1866	10.69	0.9792	2.14039	55.76
43.0697	12.75	0.6528	2.09852	66.51
47.0143	13.72	0.6528	1.93123	71.60
49.9181	5.86	0.6528	1.82548	30.57
56.8631	9.83	0.4080	1.61791	51.26
60.9527	6.62	0.6528	1.51878	34.53
62.3964	15.30	0.6528	1.48706	79.83
64.6232	5.33	0.6528	1.44109	27.78
73.5399	8.00	0.8160	1.28683	41.75
84.1957	5.94	0.4080	1.14902	30.97
84.9324	8.23	0.4080	1.14092	42.95
87.5102	8.92	0.4080	1.11383	46.54
89.2880	6.86	0.4080	1.09620	35.76
90.2595	5.30	0.9792	1.08691	27.65
94.6279	7.49	0.4896	1.04791	39.06

IV. RESULT & DISCUSSIONS

The flakiness index at 4.48% for steel slag aggregates is very low as compare to 12% of natural aggregate. This indicated that steel slag aggregates were largely consisted of rounded shape aggregates. Such character provides less angularity number, higher wokability, lesser specific surface and higher strength for particular cement content.

The elongation index of steel slag is found to be nearly same as that of natural aggregate. Although there is no specified limit of elongation index it is generally taken as equal to flakiness index.

The specific gravity of steel slag is more as compare to the natural aggregate. Though high specific gravity of an aggregate is considered as an indication of high strength, the suitability of aggregate for roads depends on its mechanical property.

Water absorption of steel slag is more as compare to natural aggregate due to its porosity. IRC has specified the maximum water absorption values as 10% of aggregates used in bituminous constructions.

Soundness test by sodium sulphate indicates loss of 11.20% which is less than 12% specified by IRC, and thus the slag can be used in bituminous surface dressing, bituminous macadam constructions.

The impact value, crushing value and abrasion value of the steel slag aggregates were all more than natural aggregate and within the IRC specifications limits. These indicated that the material possess sufficient strength for utilization as road construction aggregates.

SEM analysis determines the valuable insights of material properties and it was found that calcium, iron oxide, manganese and silicon are predominantly present in the steel slag.

In XRD analysis it is clearly observed that the most of the particles are spherical, non hydraulic and crystalline structure, with particle size varying from 0.075mm to 80mm. However the present case steel slag passing through IS sieve 20mm is used.

V. CONCLUSION

From the above results we can conclude that almost all the properties of steel slag gives satisfactory results to use it in road construction work. While its utilization for road construction it will come in contact with road water as well as road side electric poles thus we suggest to perform heavy metal leachate test as well as electrical conductivity test of steel slag must be carried out in future.

This paper is part of research work and the further work is going on to explore the possibilities to utilize the steel slag to its optimum quantity.

REFERENCES

[1] Dr. P.S. Pajgade, N.B.Thakur, “Utilisation of Waste Product of Steel Industry", International Journal of Engineering Research and Applications, Vol. 3, Issue 1, January -February 2013, pp.2033-2041

[2] Mounika M, et al, “Properties of strength and durability of concrete by partial replacement of fine aggregate with copper slag and cement with egg shell power for m30 and m40 grade of concrete” International journal of research sciences and advanced Engineering

 DOI : 10.35291/2454-9150.2019.0040

[IJRSAE]TM. Thomson Reuters Research ID: D-1153-2018, SJI Listed, Volume 2, Issue 22, PP: 65-79, APR - JUN' 2018.

[3] Mohd. Rosli Hainin, et.al, "Steel Slag as A Road Construction Material" Jurnal Teknologi (Sciences & Engineering) 73:4 (2015)

[4] MelanieHaupt, et. al, "Life cycle inventories of waste management processes" Elsevier, Volume 19, August 2018, Pages 1441-1457

[5] Standard specifications and code of practice for construction of concrete roads, IRC:15-1970, Indian Road Congress

[6] National Slag Association, "Iron and Steel making Slag Environmentally Responsible Construction Aggregates".--NSA Technical Bulletin May (2003). http://www.nationalslag.org/steelslag.htm

[7] Akyuz .S and Oner. A., "Experimental study on optimum usage of GGBS for the compressive strength of concrete", Cement & Concrete Composites Vol.29 ,pp. 505–514(2007).

[8] Binici .H ., "Performance of ground blast furnace slag and ground basaltic pumice concrete against seawater attack", Construction and Building Materials, Vol.22,pp1515-1526(2007).

[9] Dippenaar. R., "Industrial uses of slag—The use and re-use of iron and steelmaking slags". VII International Conference on Molten Slags Fluxes and Salts, The South African Institute of Mining and Metallurgy, Vol. 32,pp. 35-46 (2005).

[10] Fujii .T, Tayano.T and Sakata .K, "Freezing and thawing Resistance of Steel making slag concrete" Journal of Environmental Sciences for sustainsable society, Vol.1 ,pp.1-10(2007).

[11] Coastal Development Institute of Technology. Coastal Development Institute of Technology Library.no. 16, Manual on Steel Slag Hydrated Matrix.(2003-03).

[12] Hisahiro.M et al, "Steelmaking Technologies Contributing to Steel Industries" Concrete Jour , Vol. 41, pp.47 (2003).

 DOI : 10.35291/2454-9150.2019.0040