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RESEARCH ARTICLE

Steel Slag Utilization — Overview in Indian Perspective.

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Abstract

Current total productions of steel slag in India, are around 12 million tonnes per annum (Indian Minerals Yearbook, May 2016), which is far behind the developed countries. 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. An efficient approach to overcome these problems is the slag utilization. Physical and chemical characterization of steel slag is a deciding factor of steel slag utilization as recycled raw material as road aggregate, cement and concrete admixture, soil stabilizer and construction materials, etc. This review presents utilization trends of steel slag and possible potentials for large-scale employment of steel slag in Indian context.

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Introduction:-

Industrial Solid waste and its management is one of a most critical problem. The steel production touched 1,622.8 MT in 2015, decrease by 2.8% over 2014 (<https://www.worldsteel.org/media-centre/press-releases/2016/--World-crude-steel-output-decreases-by--2.8--in-2015.html> – accessed on 23 July 2016). Contributions from the top four steel producing countries are — China-779 MT, Japan-111 MT, USA-87 MT and India-81 MT (3.3% growth over 2012) (<https://www.ieindia.org>). The Indian integrated iron and steel industry poses serious challenges to environment through its inherent complexity (Pandey et al., 1996) and may hazardous to environment (Khan and Shinde, 2013). Presently, India is the fourth-largest manufacturer of steel (Firoz, 2014; Kumar and Naidu, 2013) following China, Japan and the US. To meet the present need of the country, steel production will be expected to increase from 99MT in 2013 to about 125MT in 2016 (Indian steel).

Presently in India, the generation of industrial solid waste by integrated iron and steel plants is nearly 270 million tonnes while, utilisation is only of 30% (<http://www.meconlimited.co.in> - accessed on 24 June 2016). Present practices for management of Indian steel industry solid wastes resulting 30% to 35% utilisation of its wastes (<https://www.ieindia.org>). Chaudhary and Pal (2002) have been reported that, 50 percent or less of the blast furnace (BF) slag is utilized for different purposes and the major amount is dumped (Chaudhary and Pal, 2002). Open dumping and landfills are some common management practices that are adopted for disposal of industrial wastes, thus resulting in environmental pollution in the form of dusts and leachate apart from huge economic accountability (Sarkar and Mazumder, 2015; Khan and Shinde, 2013). Dumping of waste on the open land causes severe

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environmental impact (Sankoh et al., 2013) and associated environmental problems are — lowering of moisture, leaching by water and pollution of nearby water sources, chemical degradation and lack of aesthetics (<http://www.cpcb.nic.in/newitems/24.pdf> - accessed on 15 June 2016). Due to high strength and durability of steel slag its suitability as construction material in many cases is superior to rock material, and use slag in construction also assist to decrease the quantity of land filled (Tossavainen, 2005). It has been reported that, iron and steel slag have high pozzolanic potential and can be utilized as raw material or blending constituent in cement manufacturing and constructional activities (Khajuria and Siddique, 2014; Huang Yi et al., 2012; Malhotra and Tehri, 1994; Kumar and Bhargavi, 2015).

Basically, steel slag is a combination of oxides of metals and silicate ([http://ibm.gov.in/writereaddata/files/11042015112113IMYB2014Slag\(Advance\).pdf](http://ibm.gov.in/writereaddata/files/11042015112113IMYB2014Slag(Advance).pdf) – accessed on 22 June 2016). According to Rajan (2014) the iron & steel slags are non metallic and does not have hazardous substances. Slag is an alternative construction material with superior environmental friendly qualities and better product features (Kumar and Kumar, 2015). Depending on the process of steel making, slag generated is called high sulfur slag, LD slag (steel furnace slag – SFS), LF slag or electric arc furnace (EAF) slag (Yildirim and Prezzi, 2011; Meng and Liu, 2000). Steel slag, and in particular LD and EAF Slag are being used extensively for different applications in many countries across the world, including USA, the European Union, Brazil, Australia and China (<http://blog.ficci.com>). As per report of the working group on cement industry for the 12th plan, approximately 10 million tonnes blast furnace slag is presently generated by iron & steel industry in the country (IMY, 2012). Blast furnace slag has high amount of SiO₂ and hence, rapidly-cooled blast-furnace slag is amorphous with pozzolanic properties (Buddhdev and Varia, 2014; Yildirim and Prezzi, 2009). Due to its beneficial cementitious and pozzolanic properties, blast-furnace slag generated each year is fully utilized by the cement and concrete industry (Yildirim and Prezzi, 2009). In contrast to blast-furnace slag, steel slag that generated from steel making and refining operations (singh et al., 2015), are not widely known and fully utilized in practice.

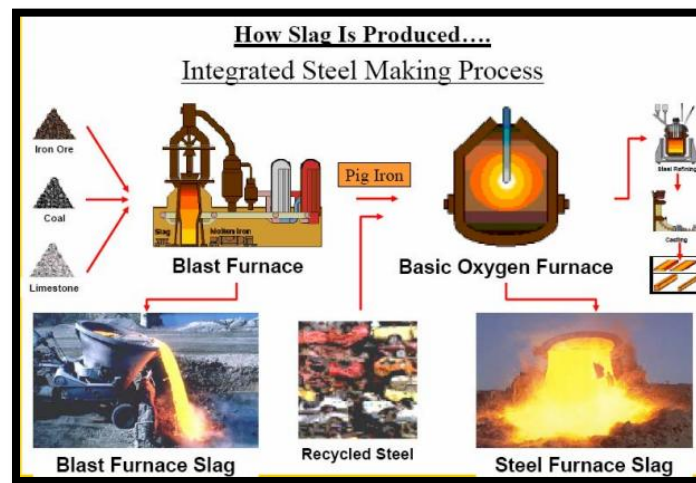


Figure 1:- Process of slag Generation (epa.gov)

During the process of reducing iron ore through coke in a blast furnace, blast furnace slag is generated while steel making slag is generated in the process of refining a hot metal produced by a blast furnace into steel (Khajuria and Siddique, 2014; Dippenaar, 2004), and has been mostly used as road material (Sen and Mishra, 2010)

Its sources are the gangue content of iron ore, that is, constituents of iron ore other than iron, and lime content added to adjust the composition of molten slag (Takahashi and Yabuta, 2002) and BF slag has been used as a component of cement (Sen and Mishra, 2010; Takahashi and Yabuta, 2002). Typically, steel slag has a very crystalline structure (application of slow cooling conditions in the processing and lacking of chemical composition of SiO₂), and for this reason, it shows weak cementitious properties (Yildirim and Prezzi, 2009). The volume stability is probably improved by water granulation in steel slag (Tossavainen, 2005) and in addition, they can possess volumetric instability in the presence of moisture (Yildirim and Prezzi, 2011). Coarse fraction (gravel-sizes) of steel slag is mainly used as road aggregates; however the problems related to its volumetric instability (Kumar and Bhargavi, 2015; Sen and Mishra, 2010). Lacks of studies that explore the engineering properties of steel slag have impeded the

utilization of steel slag in other applications in the construction industry, specifically for the finer fraction (sand and silt sizes) of steel slag (Joshi, 1997).

The amount of slag generation during pig iron and steel production is depending on composition of raw materials and type of furnace (Singh et al., 2015). One tonne of steel mean the generation of 130 – 200 kg of slag (Devi and Gnanavel, 2014). In general, blast furnace (BF) slag generation amount ranges from about 300 to 540 kg per tonne of pig or crude iron produced (Neeraja and Gopal, 2015; Singh et al., 2015) with feed of iron ore containing 60 to 65% iron (<http://ibm.nic.in>, 2013). Substandard grade of iron ores generated a large amount of slag fractions and output is approximately 20% by mass of the crude steel output (Kothai and Malathy, 2015). A locally produced steel slag, when disposed in huge amounts, may have a harmful impact on the environment.

Table 1:- Plant wise Capacity of Iron and Steel Slag in the Country (IMY, 2012)

Name of Steel Plant	Capacity for granulation (T/Year)
Bhilai Steel Plant, Durg, Chhattisgarh	2675
Bokaro Steel Plant, Bokaro, Jharkhand	5000
Rourkela Steel Plant, Rourkela, Odisha	600
Durgapur Steel Plant, Durgapur West Bengal.	N A
IISCO Steel Plant, Burnpur, West Bengal	400
Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka	6 8
Rashtriya Ispat Nigam Ltd., Visakhapatnam, Andhra Pradesh	1440
IDCOL Kalinga Iron Works Ltd, Barbil, Odisha	5 3
JSW Steel Ltd., Bellary, Karnataka	N A
Tata Steel Ltd, Jamshedpur, Jharkhand	2100
Visa Steel Ltd, Kalinganagar, Odisha	175
Neelachal Ispat Nigam LtdKalinganagar, Odisha	NA
Sona Alloys Pvt. Ltd., Satara, Maharashtra	100.8

In the steel making process there are five different kinds of slag generated (<http://ibm.nic.in>, 2013) are as under — HMT slag generated after de-siliconisation or de-phosphorisation treatment and with a high content of silica and lime and seldom includes BF slag, HMDS slag the raked slag at the desulfurisation station, which is poorly mixed composites of spill out blast furnace slag, spent and/or unreacted de-sulfurisation agents, lime fines and trapped droplet of hot metal and raked iron. LD slag , mixed aggregate of FeO, lime, silica and MgO (www.ncbindia.com/pdf_seminar/028-EA.pdf - accessed on 28 June 2016) generated at the LD converter and are in the form of di-calcium and tri-calcium silicates and contain metal and free lime responsible for expansion quality (<http://ibm.nic.in>, 2013). According to the treatment, steel slag composition changes with respect to complex calcium aluminates whose amount is less than 2% (FeO + MnO), and due to allotropic phase transformation at lower temperatures of readily crumble dust are difficult to manage. (IMY, May, 2015). SGP Slag — Granulation through a sudden quenching of molten slag, contraction of metal and slag occurs and results in better separation of metal and LD slag. Because of rapid cooling LD slag is a more glassy formation than the Basic Oxygen Furnace (BOF) slag and also elimination of free lime confirms its volumetric stability (Chand et al., 2015). BF slag and steel slag can be differentiated by presence of the amount of iron content, generally in BF slag, the amount of FeO is approximately 0.5%, while total iron content varies from 16 to 23% in steel slag, (IMY, May 2015).

Porosity and permeability of soil can be reduced by iron and steel slag (Karthik and Doraikkannan, 2015; Khan and Shinde, 2013). Leachate generation can be of great environmental concern from huge dumping of steel slag (Tiware, M. K., et al., 2015). The major issue of concern for steel slag is its unscientific dumping sites neighbouring very close to the populated area due to leachate generation. These industrial solid wastes are environmentally hazardous in nature, mainly due to release of leachate, to the human beings and also pollute soil and water (Tiware, M. K., et al., 2015a). Steel slag utilization for agricultural purposes arises the possible leaching of heavy metals and consequently the change of soil properties affects the plants (Humaria, 2014; Chand et al., 2015). Enormous quantities of steel slag are deposited in Indian slag yards, may cause environmental pollution (Chand et al., 2015). The unscientific dumping of iron and steel slag by the generators can also have harmful effects upon the aquatic environment (IMY, 2012) in the vicinity of the increase in pH of water sources, leaching of heavy metals, and rapid rates of calcite precipitation which suffocate benthic habitats (Riley and Mayes, 2015).

In India, uses of steel slag is very nominal (<http://blog.ficci.com/steel-slag/5291/> - accessed on 28 June 2016), hence steel industry slag needs to be handled carefully regarding the fact that it has the potential to turn into an environmental hazard. Presently, the utilization of these waste materials is much more crucial and of concern in India due to large amount of production and having limited application exposures. The main objective of this review is to evaluate the viability of using steel slag as a natural resource alternative and identifying valuable uses of steel slag in geotechnical applications.

Characteristics of steel slag:-

The composition of steel slag varies with the furnace type, steel grades and pre-treatment method (Devi and Gnanavel, 2014). SiO_2 , CaO , Fe_2O_3 , FeO , Al_2O_3 , MgO , MnO and P_2O_5 are the main constituents of steel slag (Motz and Geiseler, 2001; Huang et al., 2012). In steel slag the most important mineral phases are dicalcium silicate (C_2S), tricalcium silicate (C_3S), RO phase ($\text{CaO} - \text{FeO} - \text{MnO} - \text{MgO}$ solid solution), tetra-calcium aluminoferrite (C_4AF), olivine (fayalite (Fe_2SiO_4), few have kirschsteinite (CaFeSiO_4) compositions), merwinite and free lime (Kourounis et al., 2007).

The utilization approaches of steel slag are closely associated to its chemical and physical characteristics (Huang et al., 2012). Granulated blast furnace slag is a latent hydraulic material and is glassy in character (Malhotra and Tehri, 1994). Its glass content varies from 90 to 95 percent (<http://www.cpcb.nic.in>). The Steel industry in India is producing about 24 million tonnes of blast furnace slag and 12 million tonnes of steel slag annually (Singh and Murmu). Depending upon the quality, the slag is used in the range of 25-70 % in the production of Portland slag cement (PSC) (<http://www.cpcb.nic.in>; <http://www.iipnetwork.org>).

The chemical components of steel slag mainly include CaO , SiO_2 , Al_2O_3 , Fe_2O_3 , FeO , MgO , and MnO (Sharma, 2007; Jin HU et al., 2015). Chemical examination of steel slag shows the presence of a high percentage of CaO and Fe_2O_3 . CaO being 35 to 50 and Fe_2O_3 being 20 to 30 percent respectively (<http://www.cpcb.nic.in/newitems/24.pdf>). Also, the steel slag contains approximately 15 percent SiO_2 and a significant amount of MgO (about 10 percent) (<http://www.cpcb.nic.in>). The important mineral segments in steel slag are C_2S (dicalcium silicate), C_3S (tricalcium silicate), RO phase (CaO-FeO-MnOMgO solid solution), C_4AF (tetra-calcium aluminoferrite), olivine, merwinite and free lime (Kourounis et al., 2007), thus the utilization of steel slag is directly allied to its chemical and physical characteristics as reported in table 2 and 5.

Table 2:- Characteristics and applications of steel slag (Kourounis et al., 2007)

Characteristics	Application
Hard, wear-resistance, adhesive and rough	As aggregates for roads and hydraulic construction
Porous and alkaline	Waste water treatment
FeOx and its components	Iron reclamation
CaO , MgO , FeO , MgO , MnO componets	Fluxing agent
Cementitious components (C_3S , C_2S and C_4AF)	Cement and concrete production
CaO , MgO components	CO_2 capture and flue gas desulfurization
FeO , CaO , SiO_2 components	Raw material for cement clinker
Fertilizer components (CaO , SiO_2 , MgO , FeO)	Fertilizer and soil improvement

Chemical characterization of a typical Indian steel slag sample is provided in Table 3. The presence of high content of free CaO , steel slag was attributed to cause volumetric instability or un-soundness, which is limited the use of steel slag in construction (Awoyera et al., 2015).

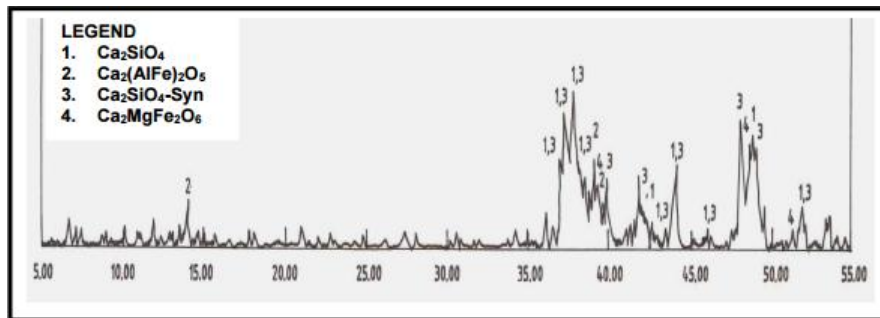
Table 3:- Chemical composition of typical Indian slag samples (<http://www.cpcb.nic.in>)

Sl. No.	Constituents	Granulated BF Slag	Steel Slag
1	Loss on ignition	0.65	2.32
2	SiO ₂	33.41	14.21
3	Fe ₂ O ₃	0.89	24.40
4	Al ₂ O ₃	20.05	4.17
5	CaO	34.24	44.32
6	MgO	8.86	10.32
7	Na ₂ O	0.16	0.08
8	K ₂ O	0.82	0.07
9	SO ₃	NIL	NIL
10	TiO ₂	NIL	1.00

Table 4:- Chemical Composition and Major Phases of Typical LD Slag Generated at Integrated Steel Plants in India (Chand et al., 2016)

Chemical composition	Major phases	wt.%
SiO ₂ – 12.16%	Tricalcium silicate (C ₃ S), Ca ₃ SiO ₅	0–20%
Al ₂ O ₃ – 1.22%	Dicalcium silicate (C ₂ S), Ca ₂ SiO ₄	30–60%
FeO – 26.30%	Other silicates	0–10%
CaO – 47.88%	Magnesiocalciowustite	15–30%
MnO – 0.28%	Dicalcium aluminoferrite (Ca ₂ (Fe, Al, Ti) ₂ O ₅)	10–25%
MgO – 0.82%	Magnesium type phase (Fe, Mn, Mg, Ca)O	0–5%
P ₂ O ₅ – 3.33%	Lime phase (Ca, Fe)O	0–15%
S – 0.28%	Periclase (Mg, Fe)O	0–5%
Na ₂ O – 0.036%	Fluorite CaF ₂	0–1%
K ₂ O – 0.071%	–	–

The XRD analysis of steel slag indicates the presence of calcium and iron-based minerals, in a way it confirms the presence of high CaO and Fe₂O₃ in the steel slag sample (Figure.2). The glass content of steel slag is very low and varies in the range of 20 to 40 percent only (<http://www.cpcb.nic.in/>).

**Figure 2:-** XRD of a Typical Steel Slag Sample (<http://www.cpcb.nic.in>)**Table 5:-** Physical Properties of Indian Steel and Blast Furnace Slag (Source: <http://pmgsy.nic.in/wastematerials.pdf>)

S. No.	Properties	Test Method	Steel Slag	Blast Furnace Slag
1	Aggregate Impact Value	IS:2386 (IV)	8 – 11%	17 – 25%
2	Los Angeles Abrasion Value	IS:2386 (IV)	8 – 10%	28 – 32%
3	Flakiness Index	IS:2386 (I)	12%	12%
4	Elongation Index	IS:2386 (I)	8%	9%
5	Water Absorption	IS:2386 (III)	1-1.6%	1.5-3%
6	Specific Gravity(Kg/cm ³)	IS:2386 (III)	3220	2650
7	Bulk Density (Kg/cm ³)	IS:2386 (III)	2100	1800

Present Utilization Trends in India:-

Iron and steel industry slag, either granulated or crystalline, is considered as a prominent and a useful raw material for developing of modern construction materials. The slag generated from different steel making processes, once treated as a useless waste but is accepted now and often, preferred and specified, as it is known to be an important material with a wide spectrum of usage, as investigated by numerous researches worldwide. The properties and composition of iron and steel slag influences its application in civil engineering construction (Dhoble and Ahmed, 2012). A wide range of application of Iron and steel slag has in building and road construction. Some popular applications of iron and steel slag are — as a raw ingredient in cement manufacturing, as aggregates, agricultural fill, glass manufacturing, as a mineral supplement and pH modifiers in soil amendment (<http://minerals.usgs.gov>). The amount of steel slag utilization is just about 15 to 20 percent of its generation, thus a huge quantities are still dumped in vicinity occupying a large area of valuable land (Vasanthi, 2014).

In last 5 years, an enhancement of over 18% for blast furnace slag and basic oxygen furnace slag has been achieved (GOI, 2013-2014). By continuing thrust on solid waste consumption at the integrated iron and steel plants, total solid waste utilization has increased from 77% in the 2007-08 to 86%; an increase of 9% over the last 5 years (GOI, 2013-2014). The major uses of steel slag in India are shown in figure 3.

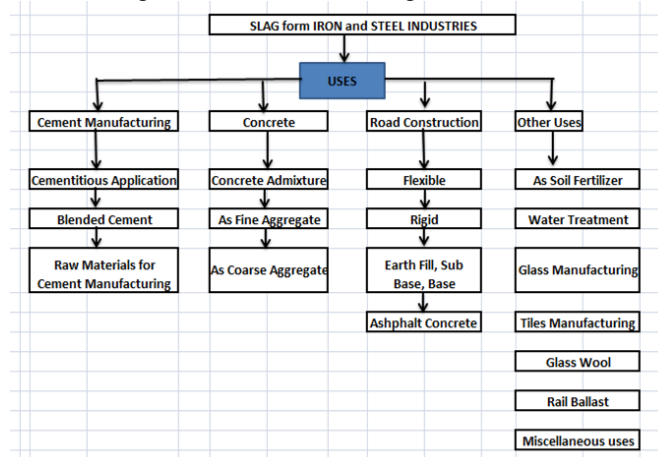


Figure 3:- Different uses of slag in India

Cement Manufacturing:-

With 130 large cement plants in the country and an installed capacity of 160.24 million tonne, India is the second largest cement producing country, with actual production achieved 141.81 million tonne during the year 2005-06 and the number of mini cement plants accounts to 365 with an installed capacity of 11.10 million tonne (<http://visioninenergy.blogspot.in/2008/11/india-ranksworlds-second-largest-cement.html>- accessed on 22 June 2016). The blast furnace slag in India is used mainly by the cement manufacturers to produce slag cement (Das et al., 2007; <http://planningcommission.gov.in> - accessed on 25 June 2016). India manufactured 270 MT of cement in 2013-2014 and by the year 2017 cement production can be expected 400 MT while for making one tonne of cement about 1.5 T lime stone is required and with about 10% replacement of limestone with BF slag creates a market for 60 MT BF slag /year, thus providing an additional possibility for 100% reuse of BF slag and also a drastic reduction of CO₂ emissions will be a bonus with reduced limestone mining also (<https://www.ieindia.org>). Granulated blast furnace slag can be utilized in the Portland slag cement (PSC) manufacturing in the proportion of 25 to 70 percent (<http://www.cpcb.nic.in>; <http://www.iipnetwork.org>), as a blending material, depending upon the quality of slag and clinker used. The steel slag can replace granulated blast furnace slag up to 10 percent in the manufacture of PSC (CPCB). The iron oxide is around 0.5% in BF slag, whereas, in case of steel slag, total iron content varies from 16 to 23% (<http://ibm.nic.in>). Indian cement industry is consuming almost the entire granulated slag produced and can consume up to 70% of the blast furnace slag generated, as less iron content in slag is suitable for the cement manufacturing (Das et al., 2007; Kothai and Malathy, 2015; IMY, May 2015). For ordinary Portland cement to make Portland slag cement, the 50:50 compositions meet all the requirements of IS 455:1989. As per Indian standard specification the increasing slag amount beyond 50 percent causes a decrease of the bare minimum compressive strength. Because of the deleterious effects of high MnO content, the slag having high MnO could not be recommended for utilization in slag cements manufacturing (Rai et al., 2002).

Table 6:- performance of blended cements prepared using industrial wastes (CPCB)

S. No.	Properties	Granulated Blast Furnace Slag	OPC [IS 12269 (1987)]
1	Fineness (M^2/kg)	350	225 (Min)
2	Setting Times (Min) IST FST	51 155	30 (Min) 600 (Max)
3	Compressive Strength (MPa) 3 days 7 days 28 days	35.0 49.5 68.7	27 37 53
4	Soundness Le-Chatelier (mm) Autoclave (%)	1 0.07	1 0.8

Apart from being more environment-friendly, the Portland slag cements inherent properties which gives several advantages over ordinary cement — ultimate compressive strength, resistance to chloride & sulphate attacks, low risk of cracking, improved workability, enhanced compatibility with all variety of admixtures, superior finish, ease of pumping, better resistance against alkali-silica reaction and also minimised shrinkage cracks (<http://www.jswcement.in>). The Portland blast furnace slag cement (PBFSC) manufacturing requires 75% less energy, less production cost and cheaper than manufacturing of the Portland cement and in recent years, the consumption of PBFSC has increased (business.mapsofindia.com).

Concrete and Road Aggregates:-

Aggregates are the key constituent of concrete occupying approximately 70 - 75% of its total volume (Devi and Gnanavel, 2014; Kothai and Malathy, 2015; Padmapriya, et al., 2015) and directly affecting the fresh & hardened properties. Silica is one of the ingredients of conventional fine aggregate used in normal concreting operations, Brindha et al. (2010) confirms the presence of a desirable amount of silica in slag is about 26%. Compressive and flexural strength along with the split tensile strength of steel slag aggregate concrete are higher than conventional concrete. It was reported that the strength of M20 and M25 concrete increases with the increase in the quantity of steel slag as a replacement, about 75 percent to normal aggregates. (Pajgade and Thakur, 2013; Brindha et al., 2010). Based on an experimental work by Nadeem and Pofale (2012), it was concluded that the steel slag could be effectively utilized as a partial replacement for fine aggregate and coarse aggregates in all types of concrete construction purposes. It was also reported that 100% replacement of naturally available crushed coarse aggregates with slag aggregates, enhanced the flexure and split tensile strength by about 6% to 8% in all grades of concrete mixes (Nadeem and Pofale (2012). In an experimental investigation by Maslehuddin (2002), it was found that the concrete with steel slag was having better physical properties than the concrete containing crushed limestone aggregate. The resistance to deflection and vertical strain will be increased by adding steel slag to the aggregates (Ahmed, 2013). The texture of the steel slag aggregate is rougher than that of the conventional, which is why the slump values for the steel slag concrete were less than that of the normal concrete (Awoyera et al., 2015). Fine aggregate replacement by steel slag shows enhanced workability compared to coarse aggregate replacement and the compressive, tensile and flexural strength of concrete was also improved with the partial replacement of fine aggregate by steel slag (Devi and Gnanavel, 2014). Steel slag aggregates have better shape, size and rough surface than conventional aggregates and thus provide improved adhesion between the particles and cement paste consequently improve the strength of concrete (Pajgade and Thakur, 2013).

Table 7:- Replacement of aggregates by steel slag to achieve Optimum strength

S. No	Author/Year	Optimum eplacement of steel slag.	Conclusions
1	Thangaselvi, 2015	60%	The increase in percentage of steel slag shows enhanced resistance to acid and sulphate attack in concrete.
2	Pajgade and Thakur, 2013	75%	It enhances the density concrete by 4 to 6% in all the concrete mixes.
3	Rajan, 2014	30%	Improvement in compressive strength is about 25%.
4	Murthi, et al., 2015	50 %	Concrete with steel slag provide high compressive strength and durability.

5	Chinnaraju, et al., 2013	60% and 40%	Total replacing of 60 percent for coarse aggregate and 40 percent for fine aggregate will suitable and not have any adverse consequence on the strength of the concrete.
6	Ravikumar, et al., 2015	60%	The 4 to 8% increase in split tensile strength and flexural strength of concrete is increases about 2 to 6% for all the grades. Steel slag can be used up to maximum of 60% replacement in all grades of concrete.
7	Padmapriya, et al., 2015	40%	Steel slag offers the maximum strength and is mostly suited for areas that are not exposed to marine conditions. Increase in strength initially is attributed to shape effect and decrease in strength beyond 40% is attributed to porosity of steel slag.
8	Saravanan, and Suganya, 2015	6%, 28% and 34%	Compressive strength of steel slag concrete increases in 6 %, Split tensile strength increases in 28 % and Flexural strength of steel slag concrete increases in 34 % steel slag replacement.
9	Subramani and Ravi, 2015	60%	Coarse aggregate replacement level of 60 % slag in concrete mixes was found to be the optimum level to obtain higher value of the strength and durability and cost reduction up to 39 %.
10	Warudkar and Nigade, 2015	75%	The optimum strength is obtained on 75% replacement by steel slag. Steel slag has increased the compressive strength, flexural strength and split tensile strength of concrete. Also it shows higher resistance to acid and sulphate attack.
11	Krishnasam and Malathy, 2014	32 %	It is found that 32 % of slag aggregate can be replaced for coarse aggregate to attain both self compactability and strength for concrete applications.
12	Kumar, and Vasudhevan, 2015	40%.	It is observed that 40% replacement level of natural sand with steel slag gives equal strength as conventional concrete.
13	Humam and Siddique, 2013	NA	Partial replacement of fine aggregates with iron slag considerably enhanced the compressive strength, splitting tensile strength, sulphate resistance and rapid chloride permeability test.
14	Bharath and Rao, 2015	50%	50% replacement of slag in M25 grade concrete offer additional strength then other proportions.
15	Jain et al.,	40 to 50%	GGBFS is found effective in reducing the expansion due to Aggregate-silica reaction in concrete due to higher alkalies binding capacity of hydration products of GGBFS.
16	Suchita Hirde et al., 2015	20%	Replacements of GGBS show considerable increase in strength and flexural tensile strength.
17	Devi and Gnanavel, 2014	40% and 30%	As fine and coarse aggregate replacement. Fine aggregate replacement gives better workability as compared to coarse aggregate replacement

Due to leaching of heavy metals and its low volumetric stability, it may create scientific and environmental barrier for the use of steel slag in road construction, but with modification of slag characteristics, these obstacles can be enhanced and uses in road construction can be augmented (Tossavainen, 2005). In India, the demand for non-building construction aggregates was expected to be about 2300 million cubic tonnes in 2015 (<http://www.aggbusiness.com>). The environmental impacts of the aggregate extraction are a source of significant concern across the nation. These impacts leading to environmental degradation due to loss of green cover, vanishing

deposits of finite resources, noise, dust, blasting and other pollution problems (Bhagwan and Guru Vittal, 2014; Maheshwarappa et al., 2015).

According to Dr. Vijay Joshi — today in India, the steel slag as a valuable material for road construction is very limited thus usage and awareness of slag utilization must be encouraged, as slag, having high durability and replacement of conventional aggregates, is sustainable in a lot of purposes. Slag is well suitable material for road construction (<http://web.iitd.ac.in>) and exceptionally strong for asphalt (Magdi and Faiza, 2015) and as other building material with characteristics such as higher durability and skid resistance. If proper support will be provided by the government of India and state authorities then steel slag can prove to be a cheaper and stronger alternate road construction material (<http://www.projectsmonitor.com>).

In India, huge amount of natural resources like soil and aggregates are being utilized for development of road projects like National Highway Development Program (NHDP), PMGSY (Pradhan Mantri Gram Sadak Yojana) and CMGSY (Chief Minister Gram Sadak Yojana) programs. This leads to resource exploitation of naturally available materials. In the 20th century, steel slag was found to be excellent aggregate as road paving material (Krishna and Venkata, 2014). Air cooled blast furnace slag, as a substitute of store aggregate /chips, has been acceded by the Indian Road Congress (IRC) and Bureau of Indian Standards (BIS) for road construction (<https://www.ieindia.org>). On the other hand, Steel slag could become unstable because of its free lime (CaO) and free magnesia (MgO) with the consequent risk of expansion (<http://pmgsy.nic.in/workshop.pdf> - accessed on 14 June 2016) Thus their use is limited in road construction and is virtually excluded from use as fill under structures. Steel slag, as construction aggregate, is recommended only in those situations where the expansion is unlikely, as in the case of dense bitumen macadam, or in the places where expansion does not cause a serious problem. Their main use, therefore, is in the upper bituminous layers of the road structure or in the surface course (Kumar et al.). Abrasion value, Impact value, crushing value and CBR values of the steel slag aggregates was found to be 30 percent, 13.90 percent, 5.20 percent, 8.27 percent and 15.57 percent respectively, well within permissible limit as per IS standards (Koranne and Valunjkar, 2015).

It was reported that the steel industry waste product is suitable and economical material for use in the road construction and the optimal mix is 15% steel slag mix in sub grade and in sub base for road construction (Zore and Valunjkar, 2010). It was also concluded in an investigation that slag may be utilized in the building of sub-grade and embankments. About 40 to 50% of slag material could be used to replace conventional aggregate for constructing layer of granular sub-base (GSB) and for bituminous layers it is not suitable (Sinha et al. 2013). Granulated blast furnace slag (GBFS) should be able to use as a partial replacement of unmodified aggregate up to 20-30% in the construction of granular sub base layers, also maximum un-soaked California Bearing Ratio (CBR) value was increased by 40.78% when 20% replacement with GBFS, whereas the 4-day soaked CBR value was increased by 46.60% (Subrahmanyam et al., 2014).

The sections of roadway in which blast furnace slag was used as a means of soft ground stabilization offers a degree of stabilization equivalent to that of the traditional method of using rock aggregate blast furnace slag which provides the following advantages when used as a coarse aggregate for sub-base (Sen and Mishra, 2010):

1. Slag that has been water quenched tends to have a lowered wear resistance and soundness;
2. For most sub base applications in which above two properties are critical, air cooled as opposed to water quenched, slag is used. In order to meet most state coarse aggregate specifications, most often air cooled slag is crushed to a ¾ inch particle size or less, once properly sized, these by-products can serve as suitable substitutes for native coarse aggregate in this application; and
3. The sections of roadway in which blast furnace slag was used as a means of providing soft ground stabilization provided a degree of stabilization equivalent to that of the traditional method of using rock aggregate.

The public works department (PWD) has permitted the utilization of iron and steel slag in construction of paved roads. In Bellary district, India, the first use of steel slag was exercised where a mega steel plants is situated (<http://planningcommission.gov.in> - accessed on 25 June 2016). Because of its expansive character due to hydration of free lime (CaO) or free magnesia (MgO), steel slag must be allowed for the weathering process before using as an aggregate in construction (Pajgade and Thakur, 2013; Mathew et al., 2013 and Lunagar and Dieu, 2015). Slag can be used for rigid pavement construction in the equal ratio with combination of manufactured sand or river sand. But it is not recommended as a 100 percent replacement of natural sand for rigid pavement works (Deccan Herald,

2016). Maximum dry density of soil increases while plasticity characteristics gradually decreases with increase in slag content and thus the CBR value of soil increases (Biradar et al., 2014; Rao et al. 2014; Singh and Ali 2014) and therefore increases soil strength. Slag content in natural soil increases its workability by reducing its liquid limit and thus its plasticity (Rao et al., 2014). It was recommended (Chaubey and Ali Jawaid, 2016) for natural soil with 25% slag as an optimum stabilization ratio for soil and can be used for sub grade as well as in construction of low permeability liners with the addition of any additives such as Bentonite.

Other usages of steel slag:-

In the current scenario, P.C.C. works, paver blocks, slag-concrete blocks, separator blocks in roads, mile stones, back fill, flexible road laying, as sub grade (Patil et al., 2016); as soil fertilizer and metal stabilization in contaminated soils (Humaria, 2014), brick making, tiles and paint manufacturing and many more are other usages of steel making slag (Pajgade and Thakur, 2013). Experts have recommended the uses of BF slag for construction works and reported that if steel slag with a chemical mixture was used as substitute of river sand by participation of different government organization as well as the public works department. It is believed that the slag is the best substitute to river sand and for the construction of roads and PWD has been using steel slag. Microscopically, river sand and granulated blast furnace slag sand is similar. The PWD had also directed the use of slag as an alternative of river sand (Rao and Bhandare, 2014) in construction of roads, besides directing all organizations functioning under it to use slag sand instead of river sand. Slag sand is comparatively cheaper than river sand (The Hindu, Mysuru, March17, 2015).

Slag Atomising Technology (SAT) of atomising molten slag is an innovative development of steel slag utilization. It is a multi-function, multi-application method with a great managerial approach to resolve environmental and technical problems by converting the slag into precious slag ball (PS balls). The PS balls are stable spinel structure that induces superior physical as well as chemical characteristics and free of any pollution issues (<http://www.meconlimited.co.in>).

Conclusion:-

Available literatures in India indicate that there is plenty of opportunity for utilization of integrated iron and steel slag. Most of the researchers have explored and focused steel slag potential as natural aggregate replacements for concrete and road construction along with cement manufacturing. It is economical to use the steel slag, as the costs of steel slag are just about 50% of that of conventional aggregates (Pajgade and Thakur, 2013). It was identified from the past researches that the steel slag is heavier than conventional aggregate, having improved friction asphalt mixtures, providing high stability (less rutting) and high angle of internal friction. Thus steel slag, instead of being disposed-off on valuable land, is suggested for use as a low-cost construction material in quality construction. Usage of steel slag in India needs to proceed cautiously, because of possible environmental, health and safety concerns. Thus, further research is needed before any specific utilization and also a final approval will be required from the government as an alternative construction material. It is anticipated that the availability of scientifically sound technology, legislation and appropriate knowledge amongst all advocates would augment the possibilities of using steel slag as an environmentally sustainable and a future substitute material for various activities.

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