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SLAG - IRON & STEEL

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GOVERNMENT OF INDIA
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INDIAN BUREAU OF MINES

Indira Bhavan, Civil Lines,
NAGPUR – 440 001

PHONE/FAX NO. (0712) 2565471
PBX : (0712) 2562649, 2560544, 2560648
E-MAIL : cme@ibm.gov.in
Website: www.ibm.gov.in

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16 Slag - Iron and Steel

Slag is a by-product generated during manufacturing of pig iron and steel. It is produced by action of various fluxes upon gangue materials within the iron ore during the process of pig iron making in blast furnace and steel manufacturing in steel melting shop. Primarily, slag consists of calcium, magnesium, manganese and aluminium silicates and oxides in various combinations. The cooling process of slag is responsible mainly for generating different types of slags required for various end-use consumers. Although the chemical composition of slag may remain unchanged, physical properties vary widely with the changing process of cooling.

In an integrated steel plant, 2-4 tonnes of wastes (including solid, liquid and gas) are generated for every tonne of steel produced. Pertinently, the concerns of today are to pay adequate emphasis on minimising waste generation, recycling and re-use of waste, and minimising the adverse impact of disposals to the environment. The major wastes produced in integrated steel plants (ISP) include BF iron slag. Total steel slag accounting for nearly more than half a tonne for each tonne of steel produced in ISPs. Among all the solid/liquid wastes, slags generated at iron making and steel making units are in such a large quantities that management of slag has become a critical component of steel production. With increasing capacities, the mechanism for disposal of large quantities of slag that get generated have gained traction as the environmental issues that it could evoke could become critical for steel makers. Over the last few years, with better understanding of slags, its functions and improvements in process technologies have led to a significant reduction in the volume of slag generated. At the same time, the re-use of iron and steel has led to a significant reduction in the environmental impact of these by-products. However, slag generation remains inevitable and emphasis on its recycling remains one of the most serious concerns that needs redressal.

PRODUCTION

The slag produced at blast furnace during pig iron manufacturing is called blast furnace slag. The slag produced at steel melting shop is known as steel slag. Slag output obtained during pig iron and steel production is variable and depends mainly on composition of raw materials and type of furnace. Typically, for ore feed containing 60 to 65% iron, blast furnace (BF) slag production ranges from about 300 to 540 kg per tonne of pig or crude iron produced, whereas in steel making 150 to 200 kg per tonne of slag is generated per tonne of liquid steel. Lower grade ores yield much higher slag fractions, sometimes as high as one tonne of slag per tonne of pig iron produced. Steel slag output is approximately 20-30% by mass of the crude steel output in the country.

Ferro Scrap Nigam Ltd (FSNL), a wholly owned subsidiary of MSTC Ltd rendering its specialised services of scrap and slag management to plants at SAIL-Rourkela, Burnpur, Bhilai, Bokaro, Durgapur, Bhadravati, Salem, RINL-Visakhapatnam, NINL-Duburi, BHEL-Haridwar, RWF (Rail Wheel Factory) - Bengaluru and also from Air India-Mumbai. During the year 2017-18 (up to Dec, 2017) recovered a scrap of 23.39 lakh tonnes.

During the year 2017-18, Tata Steel, Jharkhand & Odisha reported production of Granulated slag & BF slag at 3,754,185 tonnes & 1,406,656 tonnes, respectively. Vedanta Ltd., Goa reported production of 241,885 tonnes of Granulated slag. Bhilai steel plant reported production of 1,350,817 tonnes of granulated slag. KIC Metaliks, West Bengal reported production of 41,365 tonnes of granulated slag. Uttam Galva Mettalics reported production of 331,077 tonnes of Granulated Slag.

The information regarding plant-wise capacity of iron and steel slag in the country is given in Table- 1.

Table – 1 : Plant-wise Capacity of Iron and Steel Slag in the Country

Steel Plant	Capacity ('000 tpy)
Bhilai Steel Plant, Durg, Chhattisgarh	2675
Bokaro Steel Plant, Bokaro, Jharkhand	7884
Rourkela Steel Plant, Rourkela, Odisha	1570
Durgapur Steel Plant, Durgapur, West Bengal	566
IISCO Steel Plant, Burnpur, West Bengal	400 kg/THM*
Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka	400 kg/THM*
Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh	1440
IDCOL Kalinga Iron Works Ltd, Barbil, Odisha	53
JSW Steel Ltd, Ballari, Karnataka	NA
Tata Steel Ltd, Jamshedpur, Jharkhand	2100
Visa Steel Ltd, Kalinganagar, Odisha	175
Neelachal Ispat Nigam Ltd Kalinganagar, Odisha	-

**THM : Tonne Hot Metal*

Blast Furnace Slag

In the blast furnace, the slag floating over molten pig iron (hot metal) is flushed out in slag pot and then sent to slag granulating plant or to cooling pits.

Depending upon the cooling process, three types of slags are generated, namely, air-cooled slag, granulated slag and expanded slag.

Air-cooled slag is produced by allowing the molten slag to cool under atmospheric conditions in a pit. Under slow cooling conditions, escaping gases leave behind porous and low-density aggregates with special physical properties, making it suitable for many applications. When formed under controlled cooling, the slag tends to be hard and dense, making it especially suitable for use in ready-mixed concrete, concrete products, road bases and similar applications in construction.

Granulated slag is produced by quenching the molten slag by means of high-pressure water jets. Quenching prevents crystallisation, thus resulting in granular, glassy aggregates. This slag is crushed, pulverised and screened for use in various applications, particularly in cement production because of its pozzolanic characteristics.

Steel plants utilise cold slag for internal consumption and also for outside sale. The slag after cooling is crushed and used as road metal and railway ballast. Granulated slag produced in steel plants is also sold outside to cement plants. Slag application also reduces the overall cost of production of cement. JSPL has established Nandyal works, Andhra Pradesh & Vijaynagar works, Karnataka and Dolvi works, Maharashtra of 4.80 MTPA & 0.60 MTPA and 2.20 MTPA cement plant to produce portland slag cement (PSC) and Ground Granulated Blast Furnace Slag (GGBS) by utilising blast furnace slag as raw material.

Expanded slag is formed through controlled cooling of molten slag in water or water with combination of steam and compressed air. Formation of steam and other gases enhances the porosity and vesicular nature of slag, resulting in light weight aggregate suitable for use in concrete. However, expanded slag is not produced at any domestic iron and steel plant.

A fourth product made from blast furnace slag is mineral wool/slag wool. Cooled slag for this purpose is melted and poured through an air stream or a jet of dried stream of other gases to produce a spray of molten droplets or the same is also formed by passing the melt through a

perforated or fast-spinning disc. The droplets elongate to long fibres, which are collected mechanically and layered. The material has excellent thermal insulation properties.

The five different slags generated at various points of the steel making process are described below:

HMT Slag: This slag is primarily generated after de-siliconisation or de-phosphorisation treatment. It has high content of silica and lime. Sometimes it also contains BF slag.

HMDS Slag: This is the raked slag at the de-sulfurisation station. These slags are poorly mixed composites of spilled BF slag, spent and/or unreacted de-sulfurisation agents, lime fines and trapped droplet of hot metal and raked iron.

LD Slag: These slags are a well mixed aggregate of FeO, lime, silica and MgO generated at the LD converter. They are in the form of di-calcium and tri-calcium silicates. These slags also contain free lime and metal, which create problems due to expansion characteristics.

Steel Slag: These slags vary in composition with respect to the varied treatment. The common steel slags are fused calcium aluminates with less than 2% (FeO + MnO). These readily crumble to dust due to allotropic phase transformation at lower temperatures and are difficult to manage.

SGP Slag: LD slag is subjected to granulation through a quenching technology adopted at JSW, which houses the first of its kind in India. Due to sudden quenching of the molten slag, contraction of metal and slag occurs and results in good separation of metal and slag. Adequate granulation takes place and leads to good stability of the final slag. Process can be described as an accelerated ageing process that reduces the free lime content. Because of rapid cooling, it generates more glassy structure than the BOF slag. Removal of free lime also confirms its volumetric stability.

Steel Slag

BOF slag, commonly known as steel slag is another waste from Iron & Steel Industry. It has shown potential for use as a raw mix component up to 10% in the manufacture of cement clinker. Steel slag can also replace granulated blast furnace slag up to 10% in the manufacture of Portland Slag Cement. Steel slags are produced at steel melting shop during steel manufacturing. To produce steel, removal of excess silicon and carbon from iron is achieved through oxidation by adding limestone and coke. The steel slag contains higher amount of iron and its physical characteristics are similar to air-cooled iron slag. The LD slag is cooled, crushed and screened. The fines are utilised in sinter making and lumps are charged in the blast furnace.

The iron content is the major basic difference between BF slag and steel slag. In BF slag, FeO is around 0.70%, whereas in case of steel slag, total iron content varies from 16 to 25%.

JSW Steel has set up a unique BOF slag granulation plant, producing slag with lower free lime content and is vigorously pursuing with BIS. JSPL has set up a plant to produce around 4.0 lakh brick products/day by utilising fly ash and slag generated from integrated steel plant.

The chemical analysis of granulated BF slag and steel slag generated in steel plants is given in Table - 2.

Table – 2 : Chemical Composition of Slag Generated in Steel Plants

Name of plant	Slag	Chemical composition (%)								Physical properties
		SiO_2	Al_2O_3	CaO	MgO	MnO	FeO	S	Basicity (CaO/SiO_2)	
Bhilai Steel Plant, Durg, Chhattisgarh.	BF	34.52	20.66	32.43	10.09	0.23	0.57	0.77	–	–
	Steel	14.20	1.40	42.90	9.59	1.69	18.20	1.70	–	–
Bokaro Steel Plant, Bokaro, Jharkhand.	BF	30.06 to 31.85	21.12 to 22.71	32.48 to 34.17	10.12 to 10.39	_	0.26 to 0.37	_	_	_
	Steel	12.15 to 15.82	1.07 to 1.63	46.52 to 53.52	8.14 to 13.12	_	17.01 to 18.58	_	_	Size: 0-5 mm & 10-40 mm
Rourkela Steel Plant, Rourkela, Odisha.	BF	34.38 to 34.85	17.82 to 20.91	32.99 to 34.26	9.29 to 9.68	0.07 to 0.12	0.46 to 0.58	0.47 to 0.61	0.96 to 0.98	–
	Steel	13.7	1.82	44.4	6.7	0.81	22.6	0.09	3.28	–
Durgapur Steel Plant, Durgapur, West Bengal.	BF	32.68	21.23	32.14	–	–	–	–	–	–
	Steel	17.9	1.0	49.4	–	–	–	–	–	–
Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka.	BF	32	18	33	9	–	0.5	–	–	Size : 1 to 5mm Lumps
	Steel	30-35	1-2	35-40	9-11	–	10-15	–	–	300 mm & above
IISCO Steel Plant Burnpur, West Bengal.	BF	32.60	23.30	33.70	7.60	–	–	–	–	–
Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh.	BF	35.33	16.60	36.89	8.48	0.12	0.51	–	–	Size : -3 mm
	Steel	17.69	1.07	50.70	10.31	1.05	16.50	1.40	–	Size : +10 mm to (-)60 mm
IDCOL, Kalinga Iron Works Ltd, Barbil, Odisha.	BF	33.00 to 34.00	24.00 to 25.00	29.00 to 30.00	8.00 to 9.00	0.50 to 0.60	0.70 to 0.80	1.00	–	Size : 0 to 6 mm
Tata Steel Ltd, Jamshedpur, Jharkhand.	BF	34.5	20.8	34.3	7.3	0.052	0.6	–	–	-100 mesh to + 1 mm
	Steel	12.65	1.16	46.23	1.76	0.45	25.06	0.33	–	0 mm to + 300 mm
JSW Steel Ltd, Ballari, Karnataka	BF	35.20	19.00	34.90	8.76	0.14	(Fe) 0.039	–	–	–
Visa Steel Ltd, Kalinganagar, Odisha.	BF	33.8	15.39	35.38	10.25	0.64	0.74	0.92	–	Size : 0-5 mm & 10-40 mm
Neelachal Ispat Nigam Ltd, Kalinganagar, Odisha.	BF	32.62	32.62	33.25	9.91	0.40	0.55	0.62	–	–

Source: Returns received under Rule 45 of MCDR 2017.

USES

Slag, based on their types, has different uses. The air-cooled BF slag is crushed, screened and used mainly as road metal and bases, asphalt paving, track ballast, landfills and concrete aggregate. The expanded or foamed slag binds well with cement and is used mainly as aggregate for light weight concrete. However, it is not produced by domestic steel plants. Granulated BF slag is used as a pozzolanic material for producing portland slag cement. It is also used for soil conditioning. BF slag is used in making mineral wool for insulation purposes.

Steel slag has found use as a barrier material remedy for waste sites where heavy metals tend to leach into the surrounding environment. Steel slag forces the heavy metals to drop out of solution in water run off because of its high oxide mineral content. Steel slag has been used successfully to treat acidic water discharges from abandoned mines.

Slags are useful alternative raw material for clinker production and such use can reduce a cement plant's fuel consumption and overall emission of carbon dioxide per tonne of cement.The granulated slag obtained from various steel plants is dried in slag dryer. The clinker is ground in ball mill with 40-50% dry slag and 6% gypsum. The resultant product is portland slag cement. Portland blast furnace slag cement contains up to 60% ground granulated slag from steel production processes.

Slag cement has low heat of hydration, low alkali aggregate reaction, high resistance to chlorides and sulphate and it can substitute the use of 43 and 53 grades of ordinary Portland Cement. For other consuming sectors like road making, landfilling and ballasting, the cooled slag is crushed by machines or broken manually by hammers into smaller pieces and supplied to the various end-use consumers.

The utilisation of SMS (particularly LD) slag is limited due to its (i) Phosphorous content (ii) high free lime content and (iii) higher specific weight.

CONSUMPTION

The BF slag in India is used mainly in the cement manufacture and in other unorganised work, such as, landfills and railway ballast. A small quantity is also used by the Glass Industry for making slag wool fibres. Cement plants in the country producing slag cement require BF slag in granulated form. The chemical analysis of granulated slag consumed during the manufacture of slag cement is provided in Table-3. Also, the Consumption of slag/granulated slag in cement production for 2015-16, 2016-17 and 2017-18 is furnished in Table-4.

SAIL utilised about 88.47% and 57.55% of BF slag and LD slag, respectively, generated during April - November, 2017. SAIL also incresed BF slag utilisation by more than 1%. Around 11,90,745 tonnes of BF Slag was generated by RINL and 17,74,716 tonnes was utilised, achieved utilisation of 149.04% (up to Dec'17). Also, 4,66,582 tonnes of LD Slag was generated and 89,474 tonne was utilised in Sinter Plant, achieved utilisation of 19.18 % (up to Dec'17). TSL achieved waste utilisation of around 80% level with 100% inline BF slag granulation. A Metal recovery plant from LD slag is installed and commissioned in June 2017; steam ageing plant is under construction for non-metallic portion. The prices of BF slag vary from plant to plant. Depending upon the distance between cement plants and the steel plants, much variation is observed in prices of granulated slag.

Table – 3 : Analysis of Granulated Slag Consumed for the Manufacture of Slag Cement

Cement plant	Analysis in %								
	SiO_2	Fe_2O_3 / FeO	MgO	Al_2O_3/ MnO_2	CaO	S/SO_3	MnO	Insoluble residue	Glass content & size
ACC, Jamul, Durg, Chhattisgarh.	33.0 to 33.4	1.0 to 1.4	9.0 to 9.8	21.5 to 22.4	33.0 to 33.8	0.40 to 0.48	–	–	
ACC, Jhinkpani, W. Singhbhum, Jharkhand.	32.80	0.4	7.2	23.3	32.6	0.80	–	0.80	>79%
ACC Ltd, Bargarh Cement Works, Bardol, Bargarh, Odisha.	33.69	0.63	9.07	19.38/ 0.61	35.13	0.58	–	-	-
Andhra Cements Ltd, Visakhapatnam, Andhra Pradesh.	33.32 to 35.19	0.46 to 0.50	8.86 to 9.91	17.98 to 19.35	34.75 to 35.98	–	0.10 to 0.16	–	–
Century Cement, Baikunth, Raipur, Chhattisgarh.	–	–	5.5 (max.)	17.0 (max.)	–	2.0 (max.)	–	–	–
Penna Cement Industries Ltd, Anantapur, Andhra Pradesh.	32.00	3.50	10.0	18.50	34.92	–	–	–	size : 0-2 mm
Shri Durga Cement Co. Ltd, Hazaribagh, Jharkhand.	30.00	0.80	8.00	24.00	34.00	0.80	0.2	2.4	–

Table – 4 : Consumption of Slag/Granulated Slag in Cement Production, 2015-16 & 2017-18

(In tonnes)

Cement plant	2015-16	2016-17	2017-18
ACC Ltd, Durg, Chhattisgarh.	621643	-	-
Ambuja Cement, Gir Somnath, Gujarat.	6710	-	-
Vishnupuram, Wadapally, Nalgonda, Telangana (Granulated Slag)	31444	34414	35640
UltraTech Cement Ltd, (Rawan Cement Works) Raipur, Chhattisgarh.	493434	-	-
The RAMCO Cements Ltd, Krishna, Andhra Pradesh.	60113	-	-
The RAMCO Cements Ltd, Alathiyar, Ariyalur, Tamil Nadu.			
Granulated Slag	19848	-	-
Slag	49054	-	-
EOF Slag	45958	-	-
Vijay Cements, Trichy, Tamil Nadu.	3258	0	-
The RAMCO Cements Ltd, Govindpuram, Ariyalur, Tamil Nadu.	112239	-	-
Dalmia Cement (Bharat) Ltd, Yadwad, Belagavi, Karnataka	190	6084	-
Bagalkot Cement & Industries Ltd, Bagalkot, Karnataka.	102874	-	-

Source: Returns received under Rule 45 of MCDR 2017.

RESEARCH & DEVELOPMENT

Increased utilisation of granulated slag benefits the portland cement producers. Producers can enhance the production capacity without additional greenhouse gas emissions like carbon dioxide.

SAIL is exploring use of air cooled BF slag in construction of rigid concrete pavement in RDCIS complex.

RINL is working on Re-design of emergency containers for slag/steel dumping to eliminate the need of refractory lining.

TSL, Jamshedpur is working on utilisation of BF slags as flux in chromite pelletising along with improvement in pellet property.

Granulated BF slag may be used for cement production and other value added products. Ground granulated blast furnace slag (GBFS) is also used as a mineral additive for concrete production and substitutes for cement. Efforts are now being made to use GBFS in geo-polymer for construction purpose. The BOF slags are suitable material for the base and sub-base layer of road because of the hard characteristics. Investigation on the mineralogy and physical properties of BOF slag have shown that it would make an excellent road stone. The BOF slag of various ages has been used in the construction of the wearing course of several works and public roads. Nippon slag Association in Japan is researching converter slag utilisation in port and harbor construction and the use of EAF oxidizing slag as concrete aggregate.

The utilisation of SMS (particularly LD) slag is limited due to its (i) Phosphorous content (ii) high Free lime content and (iii) higher specific weight. To resolve these issues, Ministry of Steel has constituted a Task Force for promotion and utilisation of Iron and Steel Slag. The subject matter is also being monitored by NITI Aayog.

FOREIGN TRADE

Exports

Exports of slag (dross, etc.) in 2017-18 decreased to about 279 thousand tonnes from 385 thousand tonnes in the previous year. Exports were mainly to China (46%), Philippines (32%) and Bhutan (9%) (Table-5).

Imports

The imports of slag increased sharply to 171 thousand tonnes in 2017-18 from 114 thousand tonnes in the previous year. Imports were mainly from France (54%), Japan (28%) and Korea, Rep. of (19%) (Table-6).

Table – 5 : Exports of Slag (Dross, etc. from Iron & Steel excl. granulated) (By Countries)

Country	2016-17		2017-18	
	Qty (t)	Value (`'000)	Qty (t)	Value (`'000)
All Countries	**384821**	**1390367**	**279098**	**1032990**
China	211715	813827	128196	447874
Philippines	141054	492883	89149	345053
Bhutan	1239	4885	25590	118095
Japan	-	-	12500	43622
Nepal	26568	63153	12312	38445
Malaysia	2836	9700	10013	32607
Spain	-	-	54	2586
Qatar	++	2	840	2428
Angola	-	-	158	1016
Bahrain	-	-	140	543
Other countries	1409	5917	146	721

Table – 6 : Imports of Slag (Dross, etc. from Iron & Steel excl. granulated) (By Countries)

Country	2016-17		2017-18	
	Qty (t)	Value (`'000)	Qty (t)	Value (`'000)
All Countries	**113818**	**496506**	**171472**	**1026483**
France	-	-	91970	496507
Japan	58410	231072	47210	345684
Korea, Rep. of	55368	265103	32275	182471
Spain	-	-	17	1818
China	-	-	++	3
Vietnam Soc. Rep.	40	331	-	-

FUTURE OUTLOOK

Slag is used as substitute for clinker. This slag otherwise would have been a waste and used as a filler material. Slag, if used properly, will conserve valuable limestone deposits required for production of cement.

Portland Slag Cement (PSC) has advantages of better performance, durability and optimal production cost, besides being eco-friendly. Currently, the laws in India allow up to 65% replacement of the clinker with steel slag. It is an eco-friendly alternative as it reduces energy intensity by 30% and water demand by 12-14% for 50% slag replacement. Blended cements like PSC have multiple benefits of tangible and intangible dimensions. There is scope for further consumption of granulated slag in order to enhance the total production of cement. Slag is also a sustainable product that can be recycled and reused multiple times in various construction projects. Using iron and steel furnace slag helps to preserve our natural resources, and reduces green house gases.

Currently, the Government has plans to introduce a fourth type of cement in the market, Pozzolona Slag Cement, which will contain both steel slag and fly-ash. The potentiality for consumption of slag in cement manufacture is bound for substantial rise in near future.