71 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 manufacturing in blast furnace and steel manufacturing in steel melting shop. Primarily, the slag consists of calcium, magnesium, manganese and aluminium silicates 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.

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. 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%, by mass, of the crude steel output. Data on plantwise average generation of slag in 2008-09 and 2009-10 are given in Table-1.

The information regarding capacity and production of iron and steel slag obtained from different plants in the country is given in Table - 2.

Blast Furnace Slag

At 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 road base 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.

Table – 1: Plantwise Average Generation of Slag 2008-09 and 2009-10

(In kg/tonne of hot metal)

Steel plant	Production	
	2008-09	2009-10
Bhilai Steel Plant, Durg, Chhattisgarh.	389	395
Bokaro Steel Plant Bokaro, Jharkhand	380	380
Rourkela Steel Plant, Rourkela, Odisha.	NA	NA
Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka.	318	318
Durgapur Steel Plant, Durgapur, West Bengal.	NA	NA
IISCO Steel Plant, Burnpur, West Bengal.	475	503
IDCOL Kalinga Iron Works Ltd, Barbil, Odisha.	NA	NA
JSW Steel Ltd, Bellary, Karnataka.	NA	NA
Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh.	310	310
Tata Steel Ltd, Jamshedpur, Jharkhand.	290	290
VISA Steel Ltd. Kalingnagar,Odisha.	14	16

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. Despatches of granulated slag during 2007-08 to 2009-10 are furnished in Table-3.

Table – 2 : Plantwise Capacity and Production of Slag, 2007-08 to 2009-10

(In '000 tonnes)

	Capacity for granulation ('000 tpy)	Production								
		2007-08			2008-09			2009-10		
		BF	Granulated	Steel	BF	Granulated	Steel	BF	Granulated	Steel
Bhilai Steel Plant, Durg, Chhattisgarh.	2675	2148	1602	NA	2093	1571	NA	2119	1709	NA
Bokaro Steel Plant, Bokaro, Jharkhand.	2170	NA	NA	NA	1516	756	378	1550	819	384
Rourkela Steel Plant, Rourkela,Odisha.	600	NA	NA	NA	NA	NA	NA	NA	NA	NA
Durgapur Steel Plant, Durgapur, West Bengal.	NA	798	NA	327	NA	NA	NA	NA	NA	NA
IISCO Steel Plant Burnpur, West Bengal.	400	372	198	NA	284	164	NA	253	152	NA
Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka.	68	76	70	33	40	69	20	41	10	21
Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh.	1440	NA	NA	NA	1230	1381	NA	1209	1334	NA
IDCOL Kalinga Iron Works Ltd, Barbil,Odisha.	53	NA	NA	NA	NA	NA	NA	NA	NA	NA
JSW Steel Ltd, Bellary, Karnataka.	NA	1403	1026	691	NA	NA	NA	NA	NA	NA
Tata Steel Ltd, Jamshedpur, Jharkhand.	2100	1360	1360	1231	1814	1812	1131	2098	2069	1303
Visa Steel Ltd, Kalinganagar, Odisha	175	NA	NA	NA	NA	14	NA	NA	16	NA

Table – 3 : Despatches of Granulated Slag 2007-08 to 2009-10

(In '000 tonnes)

Steel plant	2007-08	2008-09	2009-10
Bhilai Steel Plant, Durg, Chhattisgarh.	1561	1683	1654
Bokaro Steel Plant Bokaro, Jharkhand	NA	761	808
Rourkela Steel Plant, Rourkela, Odisha.	NA	NA	NA
Durgapur Steel Plant, Durgapur, West Bengal.	536	NA	NA
IISCO Steel Plant, Burnpur, West Bengal.	199	179	170
Visvesvaraya Iron & Steel Co. Ltd, Bhadravati, Karnataka.	70	69	10
JSW Steel Ltd, Bellary, Karnataka.	1214	NA	NA
Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh.	NA	1480	1563
IDCOL, Kalinga Iron Works Ltd, Barbil, Odisha.	NA	NA	NA
Tata Steel Ltd, Jamshedpur, Jharkhand	1213	1614	2022
Visa Steel Ltd, Kalinganagar,Odisha	NA	16	32

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 lightweight 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 may be 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.

Steel Slag

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 iron content is the major basic difference between BF slag and steel slag. In BF slag, FeO is around 0.5%, whereas, in case of steel slag, total iron content varies from 16 to 23%.

The LD slag is cooled, crushed and screened. The fines are utilised in sinter making and lumps are charged in the blast furnace. The chemical analysis of granulated BF slag and steel slag generated in steel plants are given in Table - 4.

Table – 4 : 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	19.91	32.35	10.12	0.17	0.58	0.77	–	–
	Steel	14.20	1.40	42.90	9.59	1.69	18.20 (Fe)	1.70 (P_2O_5)	–	–
Bokaro Steel Plant, Bokaro, Jharkhand.	BF	34.47	18.78	32.83	10.87	0.06	0.26	0.71	–	Size : 0.6mm to 3.2 mm
	Steel	17.08 to 17.27	1.06 to 1.29	45.72 to 54.19	6.08 to 12.20	15.64 to 19.50	0.21 to 0.51	–	–	Size: 0-5 mm & 10-40 mm –
Rourkela Steel Plant, Rourkela, Odisha.	BF	33.15	22.33	30.78	10.78	0.18	0.51	0.52	–	–
Durgapur Steel Plant, Durgapur, West Bengal.	BF	33.02 to 33.23	21.75 to 22.03	32.36 to 32.55	9.08 to 9.16	– –	0.43 –	– –	0.97 to 0.98	Size : 3 mm –
	Steel	17.23	1.15	50.24	7.04	2.46	17.25	–	2.92	–
Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka.	BF	30.40 to 35.60	21.30 to 26.40	29.83 to 35.13	7.00 to 9.00	1.00 (max)	0.60 (max)	0.90 (max)	–	Size : 1 to 5 mm Lumps
	Steel	15.00	2.00	45.00	8.00	10.00	20.00	–	–	-
IISCO Steel Plant Burnpur, West Bengal.	BF	32.60	23.30	33.70	7.60	–	–	–	–	–
Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh.	BF	34.78	17.31	36.36	8.86	0.12	0.36	–	–	Size : -3 mm
	Steel	17.79	1.18	50.59	10.36	1.28	16.41	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 : up to 6 mm
Tata Steel Ltd, Jamshedpur, Jharkhand.	BF	34.28	19.03	37.09	6.54	0.06	0.53	-	–	-100 mesh to + 1 mm
	Steel	12.65	1.16	46.23	1.76	0.45	25.06 (Fe)	0.33	– 0 mm to +300 mm	
JSW Steel Ltd, Bellary, Karnataka.	BF	35.20	19.00	34.90	8.76	0.14	0.039	–	–	–
Visa Steel Ltd, Kalinganagar, Odisha	BF	31.90	19.32	35.40	8.41	–	0.36	–	–	Size : 0-5 mm & 10-40 mm

USES

Different types of slags find different uses in the industry. The air-cooled BF slag is crushed, screened and used mainly as road metal and bases, asphalt paving, railway ballast, landfills and concrete aggregate. The expanded or foamed slag binds well with cement and is used mainly as aggregate for lightweight 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 runoff 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 emmission of carbon dioxide.The granulated slag obtained from various steel plants is dried in slag dryer and ground with the clinker and gypsum in varying proportions as per the plant design. At ACC, Jamul, Chhattisgarh, raw mix containing requisite calcium carbonate with argillaceous material is burnt in the kiln by using fine coal to form clinker. The clinker thus formed is ground in ball mill with 40-50% dry slag and 6% gypsum. The resultant product is portland slag cement. At Durgapur Cement Works, the component materials; viz., clinker (procured from sister concern Satna Cement Works, Satna, Madhya Pradesh), granulated slag (prepared in slag granulation plant from BF slag of Durgapur Steel Plant) and gypsum are ground together in specified proportion in ball mill for obtaining BF slag cement.

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 BF slag is not gaining much ground because of availability of other minerals at cheaper prices than the price of BF slag.

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 forms. Only about 55% of the slag produced is consumed by the Indian Cement Industry. The chemical analysis of granulated slag consumed during the manufacture of slag cement is given in Table-5.

PRICES

The prices of BF slag vary from plant to plant. As per the information available with IBM, the price of BF slag, during 2009-10 varied from Rs. 198 to 983 per tonne. Depending upon the distance between cement plants and the steel plants, much variation is observed in prices of granulated slag. The prices of granulated slag at cement factories in 2009-10 is given in Table-6.

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.

A new granulator has been developed to cut the energy cost for granulation. This granulator consists of a variable speed rotating cup atomizer to break up the molten slag by centrifugal force and distribute it within a water-cooled cylindrical chamber. The process cools the molten slag rapidly enough to create small granules, thus minimising the need for additional crushing and grinding. Moreover, the new system offers the possibility of considerable energy recycling in the form of hot water or heated air.

Texas Industries Inc.developed a process called Chem Star for cement clinker production. The process involves the use of steel slag. In this process, steel slag is fed into the rotary clinker kiln as a part of the raw material mix. Texas Industries Inc. claimed that clinker production could be enhanced by 15% by using this process. Commonwealth Scientific & Industrial Research Organisation (CSIRO) carried out investigations for value-added method for slag and proved a number of technically viable and commercially interesting applications of slag. The applications include (i) base course and top course for asphalt roads, (ii) anti-skid surfacing for roads on accident-prone intersections, (iii) low-strength concrete for footpaths, (iv) controlled low strength fill for backfill required for trench stabilisation, and (v) concrete sub-base for rigid pavements.

The ASA Association annually undertakes an Environmental Monitoring Programme (EMP) to monitor and assess the iron & steel slag (ISS) produced,

Table – 5 : 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.	32.8 to 33.6	0.7 to 1.2	9.4 to 10.6	20.0 to 22.0	33.0 to 34.4	0.10 to 0.30	–	–	
ACC, Jhinkpani, W. Singhbhum, Jharkhand.	32.80	0.4	7.2	23.3	32.6	0.80	–	0.80	>79%
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 Cements Industries Ltd, Anantapur, Andhra Pradesh.	32.00	3.50	10.0	18.50	34.92	–	–	–	size : 0-2.00 mm
Rain Commodities Ltd, Nalgonda, Andhra Pradesh.	32.80	1.80	8.20	23.50	32.25	–	–	–	–
Shri Durga Cement Co. Ltd, Hazaribagh, Jharkhand.	30.00	0.80	8.00	24.00	34.00	0.80	0.2	2.4	–
Bargarh Cement Works, ACC Ltd, Bardol, Bargarh, Odisha.	33.69	0.63	9.07	19.38/ 0.61	35.13	0.58	–	-	-

Table – 6 : Prices of Granulated Slag at Cement Factories, 2009-10

Cement plant	Price/tonne	Source of supply
ACC, Jamul, Durg, Chhattisgarh.	392.00 198.00	(i) Bhilai Steel Plant, Durg, Chhattisgarh. (ii) NECO
Century Cement, Baikunth, Raipur, Chhattisgarh.	454	Bhilai Steel Plant, Durg, Chhattisgarh.
Dalmia Cement (Bharat) Ltd, Dalmiapuram, Tiruchirapalli, Tamil Nadu	983.46	–
OCL India Limited, Raygangpur, Sundergarh, Raigarh Odisha	795	(i) Rourkela Steel Plant, Bhilai Steel Plant, (ii) Jindal Steel & Power Ltd, Raigarh, Adhunik Metaliks, Chandrapur, RINL,Vizag, Jaiswal NECO, Mandhar etc.
Bagalkot Cement & Industries Ltd, Bagalkot, Karnataka.	732.19 700.35 671.39	i) JSW Steel Ltd, Bellary, Karnataka. ii) Kalyani Steel Ltd, Hospet, Karnataka iii) Kirloskar Ferrous India Ltd, Hospet, Karnataka
Penna Cement Industries Ltd, Boyareddipalli Anantpur (Andhra Pradesh).	788.5	JSW Cement Ltd, Chennai

processed and sold by its members. The programme invovles testing slag samples from member sites for their total metal (TM) concentration and wherever necessary, undertaking toxicity characteristic leaching procedure (TCLP) on the sample required and comparing the results against jurisdictional government regulations.

The Working Group on Cement for 11th Plan has indentified thrust areas for R&D in the Plan period. Some of these which could benefit the cause of utilisation of slags in cement industry are - coprocessing of hazardous wastes in cement manufacture, development of high performance cement based composites, utilisation of PPC for pre-stressed concrete, and utilisation of non-conventional granulated slags in cement manufacture.

FOREIGN TRADE

Exports

Exports of slag (dross, etc.) in 2009-10 increased sharply to about 670 thousand tonnes by 87% from 358 thousand tonnes in the previous year. Exports were mainly to China (90%), USA and Japan (Table-7).

Imports

The imports of slag also increased manifold to 6,497 tonnes in 2009-10 from 327 tonnes in the previous year. Imports were mainly from Japan (Table - 8).

Table – 7 : Exports of Slag (Dross, etc. from Iron & Steel, Excl. Granulated) (By Countries)

Country	2008-09		2009-10	
	Qty (t)	Value (Rs.'000)	Qty (t)	Value (Rs.'000)
All Countries	**358104**	**1151991**	**669607**	**1752831**
China	334565	1129227	602120	1617609
USA	–	–	30000	74923
Japan	–	–	23868	50031
Nepal	9078	3813	13138	9148
Oman	–	–	100	502
Bangladesh	13023	12404	198	148
Bahrain	240	1118	–	–
Belgium	73	1318	–	–
Hong Kong	1070	3787	–	–
Tanzania	35	308	–	–
Other countries	20	16	183	470

Table – 8 : Imports of Slag (Dross, etc. from Iron & Steel excl. Granulated) (By Countries)

Country	2008-09		2009-10	
	Qty (t)	Value (Rs.'000)	Qty (t)	Value (Rs.'000)
All Countries	**327**	**19835**	**6497**	**29299**
Japan	–	–	6457	29037
Georgia	–	–	40	262
China	299	19587	–	–
Germany	1	48	–	–
Pakistan	27	199	–	–
Other countries	++	1	–	–

FUTURE OUTLOOK

Slag is used as substitute to precious 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. Blended cements are in use for more than two decades in developed countries because of their multiple benefits of tangible and intangible dimensions. India is having huge slag production capacity at existing steel plants at 10 million tonnes per annum. Granulated blast furnace slag can be used to enhance production of portland cement. Demand for granulated blast furnace slag as pozzolana or cement-additive has been increasing steadily in developed countries. Hence, possibilities for export of slag can also be explored after satisfying domestic demand.

Current proposed changes in environmental rules for US cement industry (US Environmental Protection Agency, 2009) governing the manufacture of Portland cement and the characterisation of fly ash have the potential of increasing demand for slag as an alternative raw material for clinker manufacture and as an supplementary cementious materials, (SCM).

The Working Group on cement industry for the 11th Plan has stated that currently, slag cement accounts for around 10% of the total production of cement and depending upon the granulated slag availability, it would increase to 12% by the end of 11th Plan. Because of its special uses particularly in construction of bridges and constructions where the soil is alkaline, the slag is put to gainful use in cement manufacture.