

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 the 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 2006-07 and 2007-08 are given in Table-1.

The statistics 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 2006-07 and 2007-08

Steel plant	Production (In kg/tonne of hot metal)	
	2006-07	2007-08
Bhilai Steel Plant, Durg, Chhattisgarh.	404	408
Rourkela Steel Plant, Rourkela, Orissa.	NA	NA
Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka.	320	318
Durgapur Steel Plant, Durgapur, West Bengal.	362	365
IISCO Steel Plant, Burnpur, West Bengal.	509	582
IDCOL Kalinga Iron Works Ltd, Barbil, Orissa.	380	380
JSW Steel Ltd, Bellary, Karnataka.	348	412
Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh.	NA	NA
Tata Steel Ltd, Jamshedpur, Jharkhand.	239	247

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Table - 2 : Plantwise Capacity and Production of Slag, 2005-06 to 2007-08

(In '000 tonnes)

Steel plant	Capacity for granulation ('000 tpy)	Production								
		2005-06			2006-07			2007-08		
		BF	Granulated	Steel	BF	Granulated	Steel	BF	Granulated	Steel
Bhilai Steel Plant, Durg, Chhattisgarh.	2675	1975	1364	NA	1947	1345	NA	2148	1602	NA
Bokaro Steel Plant, Bokaro, Jharkhand.	2631	NA	733	NA	NA	NA	NA	NA	NA	NA
Rourkela Steel Plant, Rourkela, Orissa.	600	700	260	236	NA	NA	NA	NA	NA	NA
Durgapur Steel Plant, Durgapur, West Bengal.	NA	716	NA	323	747	NA	307	798	NA	327
IISCO Steel Plant Burnpur, West Bengal.	400	399	224	NA	394	223	NA	372	198	NA
Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka.	68	65	45	32	70	59	33	76	70	33
Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh.	1440	NA	NA	NA	NA	NA	NA	NA	NA	NA
IDCOL Kalinga Iron Works Ltd, Barbil, Orissa.	53	45	36	NA	53	42	NA	NA	NA	NA
JSW Steel Ltd., Bellary, Karnataka.	NA	NA	NA	NA	1025	677	607	1403	1026	691
Tata Steel Ltd, Jamshedpur, Jharkhand.	1400	NA	NA	NA	1328	1328	1355	1360	1360	1231

Durgapur Steel Plant (DSP) utilises cold slag for internal consumption and also for outside sale. Molten slag is sent to Durgapur Cement Works (DCW) which, in turn, granulates the molten slag. Granulated slag produced in the steel plant is also sold outside. The slag produced by Bokaro Steel Plant, after cooling, is crushed and used as road metal and railway ballast. Despatches of granulated slag during 2005-06 to 2007-08 are furnished in Table-3.

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

Table - 3 : Despatches of Granulated Slag 2005-06 to 2007-08

(In '000 tonnes)

Steel plant	2005-06	2006-07	2007-08
Bhilai Steel Plant, Durg, Chhattisgarh.	1638	1564	1561
Rourkela Steel Plant, Rourkela, Orissa.	496	NA	NA
Durgapur Steel Plant, Durgapur, West Bengal.	465	NA	536
IISCO Steel Plant, Burnpur, West Bengal.	234	241	199
Visvesvaraya Iron & Steel Co. Ltd, Bhadravati, Karnataka.	45	59	70
JSW Steel Ltd, Bellary, Karnataka.	NA	1073	1214
Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh.	NA	NA	NA
IDCOL, Kalinga Iron Works Ltd., Barbil, Orissa.	38	17	NA
Tata Steel Ltd, Jamshedpur, Jharkhand	NA	1147	1213

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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 and steel slag generated in Indian plants are given in Table - 4.

Table - 4 : Chemical Composition of Slag Generated in Indian Plants

Name of plant	Slag	Chemical composition (%)								Physical properties
		SiO ₂	Al ₂ O ₃	CaO	MgO	MnO	FeO	S	Basicity (CaO/SiO ₂)	
Bhilai Steel Plant, Durg, Chhattisgarh.	BF	34.66	19.27	31.74	11.25	0.32	0.54	0.74	-	-
	Steel	14.30	1.89	41.87	10.93	2.42	16.10	-	-	-
Bokaro Steel Plant, Bokaro, Jharkhand.	BF	32.90	19.90	32.74	10.60	0.68	0.50	0.68	0.99	
Rourkela Steel Plant, Rourkela, Orissa.	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
	Steel	15.00	2.00	45.00	8.00	10.00	20.00	-	-	Lumps
IISCO Steel Plant Burnpur, West Bengal.	BF	32.37	25.29	31.78	6.89	-	-	-	-	-
Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh.	BF	33.64	19.24	35.39	9.13	0.22	0.48	-	-	Size : -3 mm
	Steel	15.06	1.12	49.71	10.72	1.20	19.07	-	-	Size : -10 mm to +60 mm
IDCOL Kalinga Iron Works Ltd., Barbil, Orissa.	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
	Steel	14.50	0.64	51.00	1.70	0.46	18.30	0.02	-	Glass content: > 85% Size : 3.15 mm 100% 80-300 mm used in LD shops 20-80 mm BF grade scrap 0-6 mm-sinter grade
JSW Steel Ltd, Bellary, Karnataka.	BF	35.20	19.00	34.90	8.76	0.14	0.039	-	-	-

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.

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 statistics available with IBM, the price of BF slag, during 2006-07 & 2007-08 varied from Rs. 250.00 to 721.00 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 2006-07 & 2007-08 are given in Table-6.

RESEARCH & DEVELOPMENT

Increased utilisation of granulated slag benefits the portland cement producers. Producers can enhance the production capacity without generating 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

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Table - 5 : Analysis of Granulated Slag Consumed for the Manufacture of Slag Cement

Cement plant	Analysis in %								
	SiO ₂	Fe ₂ O ₃ / FeO	MgO	Al ₂ O ₃ / MnO ₂	CaO	S/SO ₃	MnO	Insoluble residue	Glass content & size
ACC, Jamul, Durg, Chhattisgarh.	33.0 to 33.4	1.00 to 01.4	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%
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 Ltd, Bardol, Bargarh, Orissa.	33.62	0.83	9.14	19.81	34.37	0.43	-	0.54	92%

Table - 6 : Prices of Granulated Slag at Cement Factories, 2006-07 and 2007-08

Cement plant	Price/tonne	Source of supply
ACC, Jamul, Durg, Chhattisgarh.	259.09	Bhilai Steel Plant, Durg, Chhattisgarh.
Century Cement, Baikunth, Raipur, Chhattisgarh.	355.59	Bhilai Steel Plant, Durg, Chhattisgarh.
Andhra Cements Ltd, Visakhapatnam, Andhra Pradesh	570.46	Visakhapatnam Steel Plant, Visakhapatnam, Andhra Pradesh.
Rain Commodities Ltd, Nalgonda, Andhra Pradesh.	721.00	Visakhapatnam Steel Plant, Visakhapatnam, Andhra Pradesh.
Penna Cement Industries Ltd, Anantapur, Andhra Pradesh.	496.31 450.00	i) JSW Steel Ltd, Bellary, Karnataka. ii) SJK Steels, Tadipatri, Andhra Pradesh.
Indorama Cement Ltd, Khar Karavi Raigad, Maharashtra.	250.00	Ispat Industries Ltd, Raigad, Maharashtra.
Mysore Cement Ltd, Ammasandra, Tumkur, Karnataka.	696.00 (Road) 706.00(Rail) 371.00(Rail)	i) JSW Steel Ltd, Bellary, Karnataka. ii) VISL, Bhadravati, Karnataka.
Zuari Cement Ltd, Krishnanagar, Cuddapah, Andhra Pradesh.	500.00	JSW Steel Ltd, Bellary, Karnataka.

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 Working Group on Cement for 11th Plan has identified 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 2007-08 increased seven times to 452,818 tonnes from 64,544 tonnes in the previous year. Exports were mainly to China (81%), UAE (11%) and Netherlands (6%) (Table - 7).

Imports

The imports of slag increased to 467 tonnes in 2007-08 from 168 tonnes in the previous year. Imports were mainly from France (Table - 8).

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

Country	2006-07		2007-08	
	Qty. (t)	Value (Rs.'000)	Qty. (t)	Value (Rs.'000)
All Countries	64544	268336	452818	987895
China	-	-	365906	908735
Netherlands	-	-	26000	40872
UAE	2040	4558	50500	23221
Saudi Arabia	-	-	7290	11488
Hong Kong	52	1275	220	1830
Nepal	375	212	2797	1364
Japan	50000	110699	-	-
Kenya	2759	264	-	-
Korea, Rep. of	9000	150564	-	-
Mexico	280	395	-	-
Other countries	38	368	105	385

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

Country	2006-07		2007-08	
	Qty (t)	Value (Rs.'000)	Qty (t)	Value (Rs.'000)
All Countries	168	2307	467	6639
France	168	2307	452	6472
China	-	-	15	167

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.

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 .