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SLAG – IRON AND STEEL

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GOVERNMENT OF INDIA
MINISTRY OF MINES
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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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, 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.

As per the Report of the Working Group on Cement Industry for the 12th Plan, around 10 million tonnes BF slag is currently generated in the country from iron & steel industry.

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

Table – 1 : Plantwise Capacity of Iron and Steel Slag in the Country

Steel Plant	Capacity for granulation ('000 tpy)
Bhilai Steel Plant, Durg, Chhattisgarh	2675
Bokaro Steel Plant, Bokaro, Jharkhand	5000
Rourkela Steel Plant, Rourkela, Odisha	600
Durgapur Steel Plant, Durgapur West Bengal.	NA
IISCO Steel Plant, Burnpur, West Bengal	400
Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka	68
Rashtriya Ispat Nigam Ltd., Visakhapatnam, Andhra Pradesh	1440
IDCOL Kalinga Iron Works Ltd, Barbil, Odisha	53
JSW Steel Ltd., Bellary, Karnataka	NA
Tata Steel Ltd, Jamshedpur, Jharkhand	2100
Visa Steel Ltd, Kalinganagar, Odisha	175
Neelachal Ispat Nigam Ltd Kalinganagar, Odisha	-
Sona Alloys Pvt. Ltd., Satara, Maharashtra	100.8

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.

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.

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 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

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 0.5%, whereas, in case of steel slag, total iron content varies from 16 to 23%.

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

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 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.

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	35.75	22.08	30.00	8.46	0.07	0.25	0.88	–	Size : 0.6mm to 3.2 mm
	Steel	16.00 to 19.00	1.07 to 1.17	45.00 to 53.00	6.00 to 11.00	0.38	18.00 to 25.00	–	–	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	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 (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	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	–	

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.

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. The chemical analysis of granulated slag consumed during the manufacture of slag cement is given in Table-3.

PRICES

The prices of BF slag vary from plant to plant. As per the information available with IBM, the price of BF slag, during 2011-12, varied from ₹ 367 to ₹ 1023 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 2011-12 are given in Table-4.

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. at Dallas, U.S. had 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 to 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, processed and sold by its members. The programme involves 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 National Slag Association has proved that iron & steel slag poses no threat to human health or to the environment. Iron & steel slags have been extensively tested using certified laboratories following USEPA and American Society for Testing materials (ASTM) procedures.

Environmental Scientists and toxicologists completed an industrywise "Human Health and Ecological Risk Assessment (HHERA) which demonstrated that iron & steel slag poses no meaningful threat to human health or environment when used in a variety of residential, agriculture, industrial and construction application. Consequently the metals in the slag matrix are not readily available for uptake by human, other animals or plants do not bioaccumulate in the foodweb and are not expected to bioconcentrate in plant tissue. Iron & steel slag may be applied safely in aquatic environment, such as rivers, lakes or streams without impacting water quality or aquatic life.

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 : Prices of Granulated Slag at Cement Factories, 2011-12

Cement plant	₹/tonne	Source of supply
ACC, Jamul, Durg, Chhattisgarh.	522	SAIL NECO, Sunflag etc.
Murli Industries Ltd, Chandrapur, Maharashtra.	1023	Fuelco Ispat (India) Ltd, Lakadganj, Nagpur, Maharashtra
OCL India Limited, Rajgangpur, Sundergarh, Odisha	751	Rourkela Steel Plant, Rourkela, Jindal Steel & Power Ltd, Raigarh, Adhunik Metaliks Kuarmundra, Bhilai Steel Plant, Bhilai
Bagalkot Cement & Industries Ltd, Bagalkot, Karnataka. Karnataka	581 431	i) JSW Cement Ltd, Bellary, Karnataka. ii) Kalyani Steel Ltd, Hospet Road, Ginizara, Koppal, iii) Kirloskar Ferrous India Ltd., Hospet, Karnataka.
Penna Cement Industries Ltd, Boyareddipalli Anantapur (Andhra Pradesh).	789	JSW Cement Ltd, Bellary
Madras Cement Ltd. Ariyalur, Tamil Nadu	839	JSW Steel Ltd, Salem
Shree Cement Ltd, Beawar, Rajasthan	367	Hindustan Zinc Ltd, Chittorgarh,Rajasthan

The study carried out by an independent nationally renowned chemical laboratory has demonstrated that blast furnace and steel slag do not pose any threat to human or plant life. The study further revealed that the use of slag has very positive environmental benefits. The use of slag in cement manufacturing significantly decreases CO_2 emission and reduces the energy neeeded to calcine limestone. The use of slag as aggregate reduces the need for virgin material and the energy use and emission produced during the mining, processing and transportation of those material.

The Working Group on Cement for 12th Plan has potential areas for R&D in the Plan period. Some of these which could benefit the cause of utilisation of slags in cement industry are: use of steel slag in road construction; use of non-conventional slags from different metallurgical industries in the manufacture of cement; and activated slag cement and tiles/bricks/blocks from slag.

FOREIGN TRADE

Exports

Exports of slag (dross, etc.) in 2011-12 increased to about 1,230 thousand tonnes by 19% from 1,030 thousand tonnes in the previous year. Exports were mainly to China (92%) and Japan (5%) (Table-5).

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

Country	2010-11		2011-12	
	Qty (t)	Value (₹'000)	Qty (t)	Value (₹'000)
All Countries	**1030569**	**4613374**	**1230450**	**7550373**
China	978819	4405692	1129614	6902679
Japan	38001	148150	58510	383397
Philippines	350	1707	39400	246141
Nepal	598	1417	1563	9174
Bhutan	-	-	955	6495
Cameroon	-	-	226	1345
Saudi Arabia	12309	55089	153	896
New Zealand	-	-	10	13
Australia	-	-	2	6
Unspecified	-	-	16	224
Other countries	492	1319	1	3

Imports

The imports of slag decreased to 17,251 tonnes in 2011-12 from 41,040 tonnes in the previous year. Imports were almost mainly from Japan and Australia (Table - 6).

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

Country	2010-11		2011-12	
	Qty (t)	Value (₹'000)	Qty (t)	Value (₹'000)
All Countries	**41040**	**269035**	**17251**	**81577**
Japan	41038	269016	9516	37418
Australia	-	-	4747	27196
Sri Lanka	-	-	2958	16832
USA	-	-	30	131
Other countries	2	19	-	-

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. Blended cements like PSC have multiple benefits of tangible and intangible dimensions. India is having huge slag production capacity of 10 million tonnes per annum at existing steel plants. Indian cement industry is consuming almost the entire granulated slag produced and can consume up to 70% of the blast furnace slag generated. There is scope for further consumption of granulated slag in order to enhance the total production of cement.

The total cement production capacity commissioned at the end of 11th Plan by 2011-12 was 331 million tpy, about 10% higher than the Plan target. By the end of 12th Plan by 2016-17, an additional capacity of 139.7 million tpy is expected to be added. This will substantially increase the potential for use of slag in the cement manufacture.