SLAG—IRON AND STEEL

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The diverse uses of iron and steel slags, coproducts of the iron and steel industry, range from construction and road building to waste stabilization. Slags are also used in cement manufacture, concrete aggregates, fill, glass manufacture, and in agriculture as soil amendment.

Slags are produced in many metallurgical operations. Iron and steel slags are produced during iron and steel manufacture. In the production of iron, the blast furnace is charged with iron ore, fluxing agents, usually limestone and dolomite, and coke as fuel. From this, molten slag and iron, are formed. Slag is produced typically at a rate of 220 to 370 kilograms per ton of pig iron. The slag is transported into a cooling pit, either directly or via iron ladles, as determined by its proximity to the furnace. The slag consists primarily of calcium, magnesium, and aluminum silicates in various combinations. Depending on the cooling method, three types of slag are produced, namely air-cooled, expanded, and granulated.

Air-cooled slag is produced by allowing the molten slag to cool in air in an open pit. The density and porosity of slag are affected by cooling rates and chemical composition. When the material solidifies under slow cooling conditions, escaping gases leave behind a porous, low- density aggregate with special physical properties, making it suitable for many applications. When formed under controlled rapid cooling (quenching), the slag tends to be hard and dense, making it especially suitable for use in road base and similar structural applications.

Expanded slag is formed through controlled rapid cooling of molten slag in water or in water with combination of steam and compressed air. Formation of steam and other gases enhance the porosity and vesicular nature of the slag resulting in a lightweight aggregate, suitable for use in concrete.

Granulated slag is produced by quenching (rapid cooling) the molten slag into glass by high-pressure water jets. Quenching prevents crystallization, thus resulting in a granular, glassy aggregate. This slag is crushed, pulverized, and screened for use in various applications, particularly in cement production, because if its pozzolanic characteristics.

Slags are also coproducts of steelmaking processes. Production of steel calls for the removal of excess silicon and carbon from iron by oxidation. Steel slag is a hard, dense material somewhat similar to air-cooled iron slag. It contains significant amounts of free iron, giving it its high density and hardness. Hardness and high density make it particularly suitable as road construction aggregate.

Legislation and Government Programs

Classification of slags under several standard waste categories has been the subject of a number of governmental initiatives. Legislatively, l996 was relatively a quiet year. According to the National Slag Association, no known major government action was recorded.

Production

Actual ferrous slag production data in the United States do not exist as the iron and steel industry does not routinely measure slag output. Consequently, the data collected by the U.S. Geological Survey (USGS) are only of the slag industry quarry sales. Slag outputs in iron and steel production are highly variable and largely depend, for the most part, on the feed chemistry and the type of furnace. Typically, for an ore feed of 60% to 66% iron, blast furnace slag production ranges from about 220 to 370 kilograms per metric ton of pig iron produced. Lower grade ores yield much higher slag fractions, sometimes as high as 1 ton of slag per ton of pig iron. Steel slag output is typically 20% by mass of the steel output. About half of this amount is entrained steel, which generally is recovered and returned to the furnace. The marketable slag after removal of the entrained steel makes up about 10 to 15% of the steel output. According to statistics reported by International Iron and Steel Institute (IISI), the U.S. pig iron production is about 50.9 million and 49.6 million tons in l995 and l996 respectively. Thus, the iron slag production for these years would range from 12 million to 13 million tons each. Likewise, U.S. steel production for l995 and l996 was reported to be 95.2 and 95 million tons respectively. This puts the expected steel slag production figures in the range from 10 million to 15 million tons.

As with the United States, there are no data on world slag production. The IISI reported world's pig iron output in l996 to be about 512 million tons and crude steel production to be 752 million tons. Estimated ferrous slag production figure from these numbers would be approximately 250 million tons.

Tables 1 through 7 present data compiled by surveying the domestic slag producers. The data for l995 reflect a response by all 17 companies queried and that for l996 a response by 16 operations. Where applicable, estimates have been incorporated for data omitted from the returned questionnaires.

Table 8 lists the production facilities that responded to the survey in l996. One minor company ceased operations, three plants closed, and seven plants from various companies did not produce any slag. International Mill Service purchased Alexander Mill Service and Koch Minerals plant was bought by Holnam Mill Service. The largest slag processor was International Mill Service with 45 plants.

Consumption

The correlation between slag production and availability is not a good indicator of consumption trends time lag between production and sale of the slag to the final customer can be significant. The primary reason for the lag is the necessity for aging the new slag to reduce its free- lime content for certain applications, such as concrete production. High levels of free-lime can adversely affect concrete performance. Generally, slag will be stored to "cure" for 6 months or longer to bring the free-lime content to acceptable levels. Furthermore, slag producers seek to keep large stockpiles to be able to participate in bids for large projects.

Air-cooled slag makes up the bulk of slag production in the United States. The total U.S. sales of about 12.2 million tons, worth $67.5 million in l996, of domestically produced air-cooled blast furnace slags recorded a slight increase of little more than 1%, over the sales in 1995, as shown in table 1. The slight increase in production was more than offset by the decrease in price. There was 7% decrease in the expanded plus granulated slag sales from those of l995. As shown in table 2, however, the overall decrease was somewhat offset by slightly higher prices. Total revenues of $141 million for l996 were about 2% lower than those of l995. As shown in table 3, the North Central region remained the leader in sales of blast furnace slags, accounting for more than 50% of tonnage and about half the revenues for the whole country.

Table 4 lists the major use of air-cooled blast furnace slags in the United States. Continued to be as aggregate for concrete and road construction. Other uses of slag were in roofing, soil conditioning, sewage treatment and mineral wool production.

Table 5 lists the l995 and 1996 use statistics for steel slag sales. Road base was the primary use followed by construction aggregates and others making up the remaining uses. The 7% decline in production from 7.1 million tons in 1995 to 6.6 million tons in 1996 translates into a 5% decline in revenues.

Transportation

As shown in table 7, the bulk of the slag was transported by truck; rail and barge transportation accounting for only about 10% of the total. Relatively short destinations, seldom exceeding 75 kilometers, make the use of trucks the preferred means of transportation.

Current Research and Technology

Recently, there has been some improvements in slag granulation systems, especially in reducing the energy costs. A granulator with a variable-speed rotating cup atomizer to break up the molten slag by centrifugal force and to distribute it within a water-cooled cylindrical chamber has been developed (Macauley, 1996). The process cools the molten slag rapidly enough to create small granules, thus minimizing the need for additional crushing and grinding. It also has the advantage of reducing the pollution associated with wet granulation as the absence of water prevents the formation of hydrogen sulfide and sulfur oxides, other than a limited quantity of sulfur dioxide emitted from the liquid slag. Moreover, the new system offers the possibility of considerable energy recovery in the form of hot water or the heated air.

Outlook

Potential classification by the U.S. Environmental Protection Agency of iron and steel slags as hazardous wastes is of constant concern to the slag industry. Otherwise, owing to its physical properties and relatively high chemical inertness, ferrous slag has a secure future in the construction industry. However, some slag plants have been closing owing to inability to compete in the market place. In the case of continuing plant closings, availability of domestic blast furnace slag may decline. This may necessitate an increase in imports. With its more limited uses, the long term-supply of steel slag appears to be more stable. We may see an increase in the use of steel slags as the blast furnace slag production experiences decline.

If a carbon tax is levied on coal consumers, the cement industry, as a coal user, may be encouraged to increase the production of blended cements in order to lower fuel consumption. This may lead to increased use of slags by the cement industry.

Reference Cited

Macauley, D., 1996, Slag Treatment - Time for an Improvement: Steel Times/Steel Times International, September, p. S15-S16.

SOURCE OF INFORMATION

National Slag Association.

TABLE 1
IRON AND STEEL SLAG SOLD OR USED IN THE UNITED STATES 1/ 2/

(Thousand metric tons and thousand dollars)

	Blast furnace slag									
	Air-cooled		Expanded 3/		Total		Steel slag		Total slag	
Year	Quantity	Value 4/	Quantity	Value 4/	Quantity	Value 4/	Quantity	Value 4/	Quantity	Value 4/
1995	12,000	68,200	1,810	53,700	13,800	122,000	7,160	22,600	21,000	144,000
1996	12,200	67,500	1,680	52,400	13,900	120,000	6,640	21,500	20,500	141,000

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Excludes imported slag.
3/ Includes granulated slag to avoid disclosing company proprietary data.
4/ Value is the selling price at plant and includes, for a few facilities, estimates reported by the plants and/or made by the U.S. Geological Survey.

TABLE 2
AVERAGE VALUE AT THE PLANT FOR IRON AND STEEL SLAG SOLD
OR USED IN THE UNITED STATES, BY TYPE

(Dollars per metric ton)

	Iron blast furnace slag				
Year	Air-cooled	Expanded 1/	Total iron slag	Steel slag	Total slag
1995	5.68	29.73	8.82	3.16	6.89
1996	5.55	31.21	8.66	3.24	6.90

1/ Includes granulated slag to avoid disclosing company proprietary data.

TABLE 3
BLAST FURNACE SLAG SOLD OR USED IN THE UNITED STATES, BY REGION AND STATE 1/ 2/

(Thousand metric tons and thousand dollars)

	1995				1996			
	Air-cooled		Total, all types		Air-cooled		Total, all types	
Region and State	Quantity	Value 3/	Quantity	Value 3/	Quantity	Value 3/	Quantity	Value 3/
North Central: Illinois, Indiana, Michigan, Ohio	7,960	44,300	8,800	60,100	7,800	43,900	8,550	59,500
Middle Atlantic: Maryland, New York, Pennsylvania, West Virginia	2,200	15,100	3,160	52,900	2,170	15,100	3,090	51,900
Other 4/	1,860	8,860	1,860	8,860	2,210	8,560	2,210	8,560
Total	12,000	68,200	13,800	122,000	12,200	67,500	13,900	120,000

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Excludes imported slag.
3/ Value based on selling price at plant.
4/ Includes Alabama, California, Kentucky, and Utah.

TABLE 4
AIR-COOLED BLAST FURNACE SLAG SOLD
OR USED IN THE UNITED STATES, BY USE 1/

(Thousand metric tons and thousand dollars)

Use	1995		1996	
	Quantity	Value 2/	Quantity	Value 2/
Asphaltic concrete aggregate	1,920	11,700	2,180	12,700
Concrete aggregate	1,140	8,360	1,390	10,000
Concrete products	327	2,190	342	2,390
Fill	1,340	4,010	1,730	6,520
Glass manufacture	W	W	W	W
Mineral wool	647	4,420	653	4,630
Railroad ballast	108	569	123	628
Road bases	5,470	30,700	4,820	24,300
Roofing, built-up and shingles	63	589	59	647
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other 3/	997	5,650	881	5,700
Total	12,000	68,200	12,200	67,500

W Withheld to avoid disclosing company proprietary data; included with "Other."
1/ Data are rounded to three significant digits; may not add to totals shown. Excludes imports.
2/ Value based on selling price at plant.
3/ Includes cement, ice control, miscellaneous, and uses indicated by symbol "W."

TABLE 5
STEEL SLAG SOLD OR USED IN THE UNITED STATES, BY USE 1/ 2/

(Thousand metric tons and thousand dollars)

Use	1995		1996	
	Quantity	Value 3/	Quantity	Value 3/
Asphaltic concrete aggregate	1,040	4,800	1,000	4,170
Fill	1,380	3,660	1,330	3,330
Railroad ballast	168	553	182	534
Road bases	2,820	7,940	2,430	8,500
Other 4/	1,760	5,630	1,700	5,020
Total	7,160	22,600	6,640	21,500

1/ Data are rounded to three significant digits; may not add to totals shown. Excludes imports.
2/ Excludes tonnage returned to furnace for charge material.
3/ Value based on selling price at plant.
4/ Includes ice control, soil conditioning, and miscellaneous uses.

TABLE 6
AVERAGE AND RANGE OF SELLING PRICES AT THE PLANT FOR IRON AND STEEL SLAG IN THE UNITED STATES IN 1996, BY USE

(Dollars per metric ton)

Use	Iron blast furnace slag 1/		Steel slag	
	Average	Range	Average	Range
Asphaltic concrete aggregate	5.83	3.99 - 11.81	4.16	2.03 - 6.69
Cement manufacture	W	W	W	W
Concrete products	6.98	W	(2/)	(2/)
Fill	3.71	.38 - 7.07	2.51	1.30 - 4.27
Glass manufacture	W	W	W	W
Mineral wool	7.08	2.79 - 9.04	W	(2/)
Railroad ballast	5.15	3.92 - 7.96	3.49	1.90 - 3.00
Road bases	5.00	.27 - 8.60	2.93	1.05 - 4.42
Roofing, built-up and shingles	10.97	5.50 - 15.00	(2/)	(2/)
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other	5.65	2.15 - 15.00	2.96	.33 - 16.46

W Withheld to avoid disclosing company proprietary data.
1/ Air-cooled slag only. Price range breakouts, by use, for granulated and expanded slag are withheld to avoid disclosing proprietary information; overall, prices ranged from $3.00 to $50.00 per ton.
2/ No use reported.

TABLE 7
SHIPMENTS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1996, BY METHOD OF TRANSPORTATION 1/ 2/

Method of transportation	Quantity (thousand metric tons)
Truck	16,500
Rail	1,000
Waterway	1,010
Total transported	18,600
Not transported (used at plant)	1,950

1/ Data are rounded to three significant digits; may not add to total shown.
2/ Excludes imported slag.

TABLE 8
PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1996

		Steel slag			Iron slag	
Company	Plant location	Basic oxygen furnace	Open hearth	Electric arc furnace	Blast furnace	Slag type
American Aggregates	Dayton, OH	X				Air-cooled.
Blue Circle Atlantic Inc.	Sparrows Point, MD				X	Granulated.
Buffalo Crushed Stone	Buffalo, NY	X				Air-cooled.
C. J. Langenfelder	Baltimore, MD	X				--
Do.	Braddock, PA	X				--
Heckett MultiServ Co.	Hickman, AR			X		--
Do.	Fontana, CA				X	Air-cooled.
Do.	Wilton, IA			X		--
Do.	Chicago, IL				X	Air-cooled.
Do.	Cook, IL			X		--
Do.	Riverdale, IL			X		--
Do.	Sterling, IL			X		--
Do.	East Chicago, IN	X				--
Do.	Indiana Harbor, IN	X				--
Do.	Ashland, KY	X			X	Air-cooled.
Do.	Coalton, KY			X		--
Do.	Newport, KY			X		--
Do.	Owensboro, KY			X		--
Do.	Kansas City, MO			X		--
Do.	Mansfield, OH	X				--
Do. (Warren Plant)	Warren, OH	X				--
Do.	do.			X		--
Do.	Youngstown, OH			X		--
Do.	Butler, PA			X		--
Do.	Provo, UT		X		X	Air-cooled.
Do.	Seattle, WA			X		--
International Mill Service	Fort Smith, AR			X		--
Do.	Kingman, AZ			X		--
Do.	Pueblo, CO	X				--
Do.	Claymont, DE			X		--
Do.	New Castle, DE			X		--
Do.	Tampa, FL			X		--
Do.	Bartow, GA			X		--
Do.	Cartersville, GA			X		--
Do.	Alton, IL			X		--
Do.	Bourbonnais, IL			X		--
Do.	Chicago, IL			X	X	Air-cooled.
Do.	Granite City, IL	X				--
Do.	Gary, IN			X		--
Do.	Huntington, IN			X		--
Do.	Laplace, LA			X		--
Do.	Jackson, MI			X		--
Do.	Monroe, MI			X		--
Do.	St. Paul, MN			X		--
Do.	Charlotte, NC			X		--
Do.	Perth Amboy, NJ			X		--
Do.	Riverton, NJ			X		--
Do.	Marion, OH			X		--
Do.	Middletown, OH	X		X		--
Do.	Mingo Junction, OH	X		X		--
Do.	Sand Springs, OK			X		--
Do.	McMinnville, OR			X		--
Do.	Portland, OR			X		--
Do.	Beaver Falls, PA			X		--
Do.	Coatesville, PA			X		--
Do.	Holsopple, PA			X		--
Do.	Midland, PA			X		--
Do.	Pricedale, PA	X		X		--
Do.	Reading, PA	X		X		--
Do.	Cayce, SC	X		X		--
Do.	Georgetown, SC	X		X		--
Do.	Jackson, TN	X		X		--
Do.	Beaumont, TX	X		X		--
Do.	El Paso, TX	X		X		--

TABLE 8--Continued
PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1996

Company	Plant location	Sleel slag			Iron slag	
		Basic oxygen furnace	Open hearth	Electric arc furnace	Blast furnace	Slag type
International Mill Service--Continued:	Jewett, TX	X		X		--
Do.	Longview, TX	X		X		--
Do.	Midlothian, TX	X		X		--
Do.	Sequin, TX	X		X		--
Do.	Plymouth, UT	X		X		--
Do.	Saukville, WI	X		X		--
Koch Minerals	Gary, IN				X	--
Do.	Weirton, WV				X	--
Lafarge Corp.	Madison, IL				X	Air-cooled.
Do.	Cleveland, OH				X	Air-cooled and expanded.
Do.	Cuyahoga, OH				X	--
Do.	Jefferson, OH				X	--
Do.	Lordstown, OH		X			Granulated.
Do.	McDonald, OH		X			--
Do.	Mingo Junction, OH				X	Air-cooled.
Do.	Trumbull, OH				X	--
Do.	Warren, OH				X	Air-cooled.
Do.	Youngstown, OH		X			--
Do. (Brown Reserve)	Allegheny, PA				X	--
Do.	do.				X	--
Do.	Beaver, PA				X	--
Do.	West Aliquippa, PA				X	--
Do.	West Mifflin, PA				X	Air-cooled.
Do. (Duquesne)	do.	X	X		X	Do.
Do.	Brooke, WV				X	--
Do.	do.				X	--
Do.	Weirton, WV				X	Air-cooled.
Edward C. Levy Co.	Detroit, MI	X		X	X	Air-cooled and expanded.
The Levy Co. Inc.	Burns Harbor, IN	X			X	Air-cooled.
Do.	East Chicago, IN				X	Do.
Maryland Slag Co.	Sparrows Point, MD				X	Do.
Stein, Inc.	Cleveland, OH	X				--
Do.	Lorain, OH	X			X	Air-cooled.
United Slag Co.	Rancho Cucamonga, CA			X		--
Vulcan	Alabama City, AL				X	Air-cooled.
Do.	Fairfield, AL	X			X	Do.
Waylite Corp.	Bethlehem, PA	X	X		X	Air-cooled and expanded.