SLAG—IRON AND STEEL

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Slags, which are nonmetallic byproducts of many metallurgical operations, consist primarily of calcium, magnesium, and aluminum silicates in various combinations. Iron and steel slags are coproducts of iron and steel manufacturing.

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. The slag is transported into a cooling pit, either directly or via iron ladles, depending on the distance between the pit and the furnace. The physical characteristics, density, porosity, and particle size of slag are affected by the cooling rates and chemical composition. Depending on the cooling method, three types of iron slag are produced— air-cooled, expanded, and granulated. Air-cooled slag is produced by allowing the molten slag to cool slowly in air in an open pit. When the material solidifies under slow cooling conditions, escaping gases leave behind a porous, low-density aggregate. When formed under controlled rapid cooling in air (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 a combination of steam and compressed air. 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 using high-pressure water jets. Quenching prevents the crystallization of minerals constituting the slag composition, thus resulting in a granular, glassy aggregate. This slag is crushed, pulverized, and screened for use in various applications, particularly in cement production, because of its pozzolanic (hydraulic cementitious property) characteristics.

Slags are also coproducts of steelmaking processes. Production of steel calls for the removal of excess silicon by mineralization and carbon by oxidation from pig or crude iron. 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.

Uses of iron and steel slags range from building and road construction to waste stabilization. Iron and steel slags are also used in cement manufacture, concrete aggregates, fill, glass manufacture, and agriculture as a soil amendment (as a mineral supplement and liming agent).

Legislation and Government Programs

Classification of slags under several standard waste categories has been the subject of a number of past governmental initiatives. The National Slag Association, however, reported no major government action concerning slag in 1997 (R.Y. Twitmyer, written commun., National Slag Association, 1998). The passage of the National Highway Infrastructure Act, with its $217 billion spending plan, by Congress may play a significant role in slag consumption; prices of ferrous slags used in highway construction may be affected.

Production

Actual ferrous slag production data in the United States do not exist, because 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 sales, rather than the output. Slag outputs in iron and steel production are highly variable and depend, for the most part, on the feed chemistry and the type of furnace. Typically, for an ore feed with 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 metric ton of slag per ton of pig iron. Steel slag outputs are approximately 20% by mass of the steel output. About half of this amount is entrained steel, is which generally recovered and returned to the furnace. After removal of the entrained steel, the marketable slag makes up about 10% to 15% of the steel output.

According to statistics reported by the American Iron and Steel Institute (AISI) (International Iron and Steel Institute, Brussels, written commun., 1998), the U.S. pig iron production was about 50 million and 49 million metric tons in l997 and l996, respectively. Thus, the iron slag production for these years was about 13 million tons in 1997 and 12 million tons in 1996. Similarly, U.S. steel production for l997 and l996 was reported to be 98 and 96 million tons, respectively. The expected steel slag production was about 17 million tons in 1997 and 15 million tons in 1996. As with the United States, no data are available on world slag production. The International Iron Steel Institute reported the world pig iron output in l997 to be about 597 million tons and crude steel production to be 862 million tons. The estimated ferrous slag production figure from this output is approximately 270 million tons.

Tables 1 through 7 list data compiled by surveying the domestic slag producers. The data for both l996 and 1997 reflect a response by 95% of slag processors queried. 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 l997. Lafarge Corp. has acquired Redland Mill Services. Olympic Mill Services, a new slag processor, has emerged as a major player in slag business, but the company's sales data were not available for the 1997 survey.

Consumption

The correlation between slag production and availability is not a good indicator of consumption trends because time lags 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, especially steel slag, will be stored to "cure" for 6 months or longer to allow expansion of dicalcium silicate and to reduce the free-lime content to acceptable levels. Furthermore, slag producers seek to accumulate large stockpiles to be able to participate in bids to supply large construction projects.

Air-cooled slag composed the bulk of slag production (sales) in the United States. The total U.S. sales of about 10.1 million tons, worth $68 million in l997, of domestically produced air-cooled blast furnace slag recorded a 2% decrease from those of 1996. *(See table 1.)* The slight decrease in production was offset by the increase in price. Expanded and granulated slag sales remained about the same as those of 1996. Increase in prices resulted in a 4% rise in revenues. *(See table 2.)* Total revenues of $146 million (iron slags plus steel slags) for l997 were about 3.5% higher than those of l996. 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, with the Middle Atlantic region making up the bulk of the remaining business. *(See table 3.)*

In the United States, sales for roofing and concrete road construction, including road base, accounted for the consumption of more than one-half the air-cooled blast furnace slags. Other uses were in soil conditioning, sewage treatment and mineral wool production. *(See table 4.)*

As in the case of blast furnace slags, road base was the primary use of steel slag, followed by fill and construction aggregates. The 6% increase in sales from 6.6 million tons in 1996 to 7.0 million tons in 1997 translates into almost a 13% rise in 1997 revenues over the 1996 figures. *(See table 5.)*

Transportation

Bulk of the almost 18 million tons of ferrous slag was transported by truck; rail and barge transportation accounted for only 11% of the total. *(See table 7.)* Relatively short destinations (distances up to 100 kilometers), dictated by transportation costs, make trucks the preferred means of transportation.

Current Research and Technology

Slag processing is an established, conservative industry and all the slag processed is readily sold. Therefore, the industry seldom feels the need for innovations, and, thus, significant innovations in slag processing seldom are made. Recently, however, some improvements in slag granulation systems, especially in reducing the energy costs have been made. 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 is claimed to have the advantage of reducing the pollution associated with wet granulation because the absence of water prevents the formation of hydrogen sulfide and sulfur oxides, except for 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 heated air.

Texas Industries (TXI) has developed a process for cement clinker production involving the use of steel slag. In this process, called CemStar, steel slag is fed into the rotary kiln as a part of the raw meal. The company claimed that clinker production should be enhanced by as much as 15% (Robert T. Rogers, TXI, oral communication).

Outlook

Nucor Corp. announced plans to construct a new 1-million-ton-per-year electric arc furnace steel mill to produce steel plate using the latest technologies. (Nucor Corporation, June 1, 1998, Nucor plans to construct a steel mill to produce steel plate in Hertford County, North Carolina, accessed June 1, 1998, at URL http://biz.yahoo.com/prnews/980601/nc_nucor_n_1.html). Production may increase to processing of 200,000 metric per year.

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 high chemical inertness, ferrous slag has a secure future in the construction industry. Some blast furnace operations, however, have been closing owing to an 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. An increase in the use of steel slags may be on the horizon as the blast furnace slag production experiences a decline.

A potential carbon tax, levied on fossil fuels, may force the cement industry to increase the production of blended cements, including those using slags, to reduce carbon dioxide emissions from fossil fuel combination and the calcination of limestone.

Reference Cited

Macauley, David, 1996, Slag treatment—Time for an improvement: Steel Times/Steel Times International, September, p. S15-S16.

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/
1996	12,175	67,500	1,680	52,400	13,900	120,000	6,640	21,500	20,500	141,000
1997	10,100	67,800	1,760	53,800	11,900	122,000	7,040	24,300	18,900	146,000

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
1996	5.55	31.21	8.66	3.24	6.90
1997	6.71	32.87	10.25	3.46	7.72

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)

	1996				1997			
	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	7,800	43,900	8,550	59,500	6,440	46,400	7,270	62,800
Middle Atlantic: Maryland, New York, Pennsylvania West Virginia	2,170	15,100	3,090	51,900	2,070	12,400	3,010	49,900
Other 4/	2,210	8,560	2,210	8,560	1,590	8,950	1,590	8,950
Total	12,200	67,500	13,900	120,000	10,100	67,800	11,900	122,000

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	1996 Quantity	1996 Value 2/	1997 Quantity	1997 Value 2/
Asphaltic concrete aggregate	2,180	12,700	2,380	13,500
Concrete aggregate	1,390	10,000	1,310	19,300
Concrete products	343	2,390	157	1,160
Fill	1,730	6,520	1,220	3,690
Glass manufacture	W	W	W	W
Mineral wool	653	4,630	555	4,030
Railroad ballast	123	628	134	749
Road bases	4,820	24,300	3,400	19,600
Roofing, built-up and shingles	59	647	54	578
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other 3/	880	5,700	901	5,130
Total	12,200	67,500	10,100	67,800

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	1996 Quantity	1996 Value 3/	1997 Quantity	1997 Value 3/
Asphaltic concrete aggregate	1,000	4,170	1,870	7,780
Fill	1,330	3,330	1,940	5,230
Railroad ballast	182	534	182	578
Road bases	2,430	8,500	1,640	5,890
Other 4/	1,700	5,020	1,400	4,850
Total	6,640	21,500	7,040	24,300

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 1997, BY USE

(Dollars per metric ton)

Use	Iron blast furnace slag 1/ Average	Iron blast furnace slag 1/ Range	Steel slag Average	Steel slag Range
Asphaltic concrete aggregate	5.69	3.55 - 12.00	4.16	1.52 - 4.89
Cement manufacture	W	W	W	W
Concrete products	7.39	3.99 - 9.23	(2/)	(2/)
Fill	3.02	.43 - 7.69	2.69	.97 - 15.00
Glass manufacture	W	W	W	W
Mineral wool	7.25	3.91 - 9.51	W	(2/)
Railroad ballast	5.59	3.26 - 6.50	3.18	2.64 - 3.00
Road bases	5.77	1.93 - 9.23	3.58	1.02 - 4.82
Roofing, built-up and shingles	10.70	3.39 - 15.80	(2/)	(2/)
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other	6.40	3.00 - 7.57	3.46	.33 - 5.37

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 1997, BY METHOD OF TRANSPORTATION 1/ 2/

Method of transportation	Quantity (thousand metric tons)
Truck	16,000
Rail	699
Waterway	1,020
Total transported	17,700
Not transported (used at plant)	1,200

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 1997

Company	Plant location	Steel slag: Basic oxygen furnace	Steel slag: Open hearth	Steel slag: Electric arc furnace	Iron slag: Blast furnace	Iron slag: Slag type
American Aggregates	Dayton, OH	X	--	--	X	Air cooled.
Blue Circle Atlantic Inc.	Sparrows Point, MD	--	--	--	X	Granulated.
Buffalo Crushed Stone	Buffalo, NY	X	--	--	X	Air cooled.
C. J. Langenfelder	Baltimore, MD	X	--	--	--	--
Do.	Braddock, PA	X	--	--	--	--
Heckett MultiServ Co.	Armorel, AR	--	--	X	--	--
Do.	Blytheville, AR	--	--	X	--	--
Do.	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.	Wilder, KY	--	--	X	--	--
Do.	Kansas City, MO	--	--	X	--	--
Do.	Mansfield, OH	X	--	--	--	--
Do.	Massillon, OH	--	--	X	--	--
Do.	Warren, OH	X	--	--	--	--
Do.	do.	--	--	X	--	--
Do.	Youngstown, OH	--	--	X	--	--
Do.	Butler, PA	--	--	X	--	--
Do.	Koppel, 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.	Cartersville, GA	--	--	X	--	--
Do.	Alton, IL	--	--	X	--	--
Do.	Chicago, IL	--	--	X	X	Air cooled.
Do.	Kankakee, 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.	Jackson, MS	--	--	X	--	--

TABLE 8--Continued
PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1997

Company	Plant location	Steel slag: Basic oxygen furnace	Steel slag: Open hearth	Steel slag: Electric arc furnace	Iron slag: Blast furnace	Iron slag: Slag type
International Mill Service--Continued:	Charlotte, NC	--	--	X	--	--
Do.	Auburn, NJ	--	--	X	--	--
Do.	Perth Amboy, NJ	--	--	X	--	--
Do.	Riverton, NJ	--	--	X	--	--
Do.	Hubbard, OH	--	--	X	--	--
Do.	Marion, OH	--	--	X	--	--
Do.	Middletown, OH	X	--	X	--	--
Do.	Mingo Junction, OH	X	--	X	--	--
Do.	McMinnville, OR	--	--	X	--	--
Do.	Portland, OR	--	--	X	--	--
Do.	Beaver Falls, PA	--	--	X	--	--
Do.	Brideville, PA	--	--	X	--	--
Do.	Coatesville, PA	--	--	X	--	--
Do.	Holsopple, PA	--	--	X	--	--
Do.	New Castle, PA	--	--	X	--	--
Do.	Midland, PA	--	--	X	--	--
Do.	Pricedale, PA	X	--	X	--	--
Do.	Reading, PA	X	--	X	--	--
Do.	Cayce, SC	X	--	X	--	--
Do.	Darlington. SC	X	--	X	--	--
Do.	Georgetown, SC	X	--	X	--	--
Do.	Jackson, TN	X	--	X	--	--
Do.	Beaumont, TX	X	--	X	--	--
Do.	El Paso, TX	X	--	X	--	--
Do.	Jewett, TX	X	--	X	--	--
Do.	Longview, TX	X	--	X	--	--
Do.	Midlothian, TX	X	--	X	--	--
Do.	Plymouth, UT	X	--	X	--	--
Do.	Seattle, WA	X	--	X	--	--
Do.	Saukville, WI	X	--	X	--	--
Do.	Weirton, WV	X	--	X	--	--
Koch Minerals	Gary, IN	--	--	--	X	Air cooled, granulated, and expanded.
Do.	Weirton, WV	--	--	--	X	Granulated.
Lafarge Corp.	Granite City, IL	X	--	--	X	Air cooled.
Do.	Cleveland, OH	--	--	--	X	Air cooled and expanded.
Do.	Cuyahoga, OH	--	X	--	--	--
Do.	Lordstown, OH	--	X	--	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.	West Mifflin, PA	--	--	--	X	Air cooled.
Do.	Weirton, WV	--	--	--	X	Do.
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.	Decatur, AL	--	--	X	--	--
Do.	Cleveland, OH	X	--	--	--	--
Do.	Lorain, OH	X	--	--	X	Air cooled.
Vulcan	Alabama City, AL	--	--	--	X	Do.
Do.	Fairfield, AL	X	--	--	X	Do.
Waylite Corp.	Bethlehem, PA	X	X	--	X	Air cooled and expanded.
Do.	Cambria, PA	--	X	X	X	Air cooled.