SLAG—IRON AND STEEL

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Domestic survey data and tables were prepared by Robin Kaiser, statistical assistant.

To the casual observer, one of the most striking features of an iron and steel plant is the site of a mountainous pile that presents a continuous display as ladle after ladle pours its incandescent load down the side in the endless accumulation of a waste product called slag. Almost a century ago, the term "waste product" aptly described slag. Slag was considered to be essential in the production of iron, but once it served its purpose in the refining of the metal, it was strictly a nuisance with little or no use. The usefulness of slags first became apparent as early as the turn of the 19th century in Europe where the incentive to make all possible use of industrial byproducts was strong. Shortly after, many markets for slags opened in the United States and elsewhere in the world.

Slags are nonmetallic byproducts of many metallurgical operations and 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 and the reducing agent. The iron ore is a mixture of iron oxides, silica, and alumina. From this and the added fluxing agents, molten slag and iron are formed. Oxygen in the preheated air blown into the furnace combines with the carbon of the coke to produce the needed heat and carbon monoxide. At the same time, the iron ore is reduced to iron, mainly through the reaction of the carbon monoxide with the iron oxide to yield carbon dioxide and metallic miron carbon. The fluxing agents dissociate into calcium and magnesium oxides and carbon dioxide. The oxides of calcium and magnesium combine with silica and alumina to form slag. 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 such as density, porosity, and particle size, 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 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.

Upon crushing and screening, air-cooled blast furnace slag has physical properties that make it particularly suitable as an aggregate. It breaks to give a cubical shape and a rough surface morphology with good frictional properties and good adhesion to bituminous and cement binders; a low coefficient of thermal expansion; and good fire resistance. It has a high water absorption owing largely to its porosity. These characteristics give it the best resistance of all aggregates to stripping of the binder caused by the combined action of water and traffic.

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 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, which make it particularly suitable as road construction aggregate.

Slag formed by using one of the methods is transported to processing plants where it undergoes crushing, grinding, and screening operations to meet various use specifications. Processed slag is either shipped to its buyer for immediate use or stored.

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 1998 (R.Y. Twitmyer, President, National Slag Association, oral commun., 1999). The passage of the Transportation Equity Act by the U.S. Congress in 1998, with its $205 billion spending plan, may play a significant role in slag consumption; prices of ferrous slags used in highway construction may be favorably 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 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 chemistry of the raw materials 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 (t) of slag per 1 t of pig iron. Steel slag outputs are approximately 20% by mass of the steel output. About half of it is entrained steel, which is 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 International Iron and Steel Institute (IISI), Brussels, the U.S. pig iron production was about 53 million and 55 million metric tons (Mt) in l998 and l997, respectively (Steel Statistical Yearbook, IISI, Brussels, Belgium, 1998). Thus, the iron slag production for these years was about 12.5 and 13 Mt in 1998 and 1997, respectively. United States steel production for l998 and l997 was reported to be 108 and 107 Mt, respectively. The expected steel slag production was about 17.2 and 17 Mt in 1998 and 1997, respectively. As with the United States, no data are available on world slag production. The IISI reported the world pig iron output to be about 544 Mt and crude steel production to be 783 Mt in 1998. The estimated figures for ferrous slag production from this output was approximately 200 Mt.

Tables 1 through 8 list data compiled from the survey of the domestic slag producers. The data for l997 and 1998 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 l998. Lafarge Corp. acquired Redland Mill Services. Olympic Mill Services, a new slag processor, emerged as a major player in slag the business. The company’s sales data were not available for the 1997 survey, but were for the 1998 survey.

Consumption

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, agricultural fill, and glass manufacture and as mineral supplements and liming agents in soil amendments in agriculture.

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, many slag producers 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 10.3 Mt, worth more than $63 million, of domestically produced air-cooled blast furnace slag recorded a slight increase in tonnage but a 9% loss in revenues in 1998 compared with those of 1997 (table 1). Expanded and granulated slag sales increased to 1.9 Mt in 1998 from 1.8 Mt in 1997. Increases in prices and the tonnage sold resulted in a more than 19% rise in revenues (table 2). Total revenues of $150 million (iron slags plus steel slags) for l998 were about 9.5% higher than those of l997. The Mid-Atlantic Region replaced the North-Central Region as the new leader in sales of blast furnace slags, accounting for almost 50% of total revenues for the whole country, with the North-Central region making up the bulk of the remaining business (table 3).

In 1998, sales for roofing and concrete road construction, including road base, again accounted for more than one-half the consumption of air-cooled blast furnace slags in the United States; other uses were in soil conditioning, sewage treatment, and mineral wool production (table 4).

As in the case of blast furnace slags, road base was the primary use of steel slag, followed by construction aggregates and fill. The 12% decrease in sales to almost 6.2 Mt in 1998 from more than 7.0 Mt in 1997 translates into an 8% decrease in 1998 revenues (table 5). Slag prices showed a wide range of values depending on their use categories (table 6).

Transportation

Most of the 18 Mt of ferrous slag was transported by truck; rail and barge transportation accounted for only 10% of the total (table 7). Most ferrous slag was transported less than 100 kilometers; trucks were the most economical means of transportation for such distances.

Current Research and Technology

Because slag processing is an established, conservative industry, all the slag that is processed is readily sold. Therefore, the industry seldom feels the need for innovations. Recently, however, some improvements have been made in slag granulation systems, especially in reducing the energy costs. A granulator with a variable-speed rotating cup atomizer has been developed. The atomizer breaks up the molten slag by centrifugal force and distributes it within a water-cooled cylindrical chamber (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. The new system also offers the possibility of considerable energy recovery in the form of hot water or heated air.

Texas Industries 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 D. Rogers, President, Texas Industries, oral commun., 1998).

Outlook

Nucor Corporation 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 tons per year of slag.

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. With such a classification and 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 because of an inability to compete in the market place. In the case of continuing plant closings, availability of domestic blast furnace slag may decline, which 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 blast furnace slag production declines.

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 fuel consumption.

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/
1997	10,100	57,900 r/	1,760	53,800	11,900	112,000 r/	7,040	24,900 r/	18,900	137,000 r/
1998	10,300	63,100	1,920	64,400	12,200	127,000	6,180	22,900	18,400	150,000

r/ Revised.

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
1997	5.73 r/	30.57 r/	9.41	3.54 r/	$7.23 r/
1998	6.12	33.57	10.43	3.71	$8.18

r/ Revised.

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)

	1997				1998			
	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	6,440	36,500 r/	7,270	52,857 r/	6,280	37,100	7,160	53,900
Mid-Atlantic: Maryland, New York, Pennsylvania, West Virginia	2,070	12,400	3,010	49,900	1,990	14,800	3,030	62,400
Other 4/	1,590	8,950	1,590	8,950	2,030	11,200	2,030	11,200
Total	10,100	57,900 r/	11,900	112,000 r/	10,300	63,100	12,200	127,000

r/ Revised.

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, Mississippi, 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	1997 Quantity	1997 Value 2/	1998 Quantity	1998 Value 2/
Asphaltic concrete aggregate	2,380	13,500	1,790	11,300
Concrete aggregate	1,310	9,400 r/	1,260	9,090
Concrete products	157	1,160	198	1,330
Fill	1,220	3,690	1,540	8,110
Glass manufacture	W	W	W	W
Mineral wool	555	4,030	483	3,750
Railroad ballast	134	749	83	425
Road bases	3,400	19,600	4,140	22,500
Roofing, built-up and shingles	54	578	49	586
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other 3/	901	5,130	754	5,990
Total	10,100	57,900 r/	10,300	63,100

r/ Revised. 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	1997 Quantity	1997 Value 3/	1998 Quantity	1998 Value 3/
Asphaltic concrete aggregate	1,870	7,780	1,110	5,620
Fill	1,940	5,000 r/	1,390	3,400
Railroad ballast	182	578	171	530
Road bases	1,640	5,890	2,450	8,330
Other 4/	1,400	5,690 r/	1,060	5,060
Total	7,040	24,900 r/	6,180	22,900

r/ Revised.
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 1998, BY USE

(Dollars per metric ton)

Use	Iron blast furnace slag 1/		Steel slag	
	Average	Range	Average	Range
Asphaltic concrete aggregate	6.31	4.31-11.81	4.94	1.96-6.90
Cement manufacture	W	W	W	W
Concrete products	6.72	4.65-9.39	(2/)	(2/)
Fill	5.26	2.10-7.43	2.24	.69-4.00
Glass manufacture	W	W	W	W
Mineral wool	7.75	3.50-9.88	W	(2/)
Railroad ballast	5.12	3.31-8.00	3.56	2.25-21.60
Road bases	5.44	2.43-9.39	3.40	.75-11.50
Roofing, built-up and shingles	11.96	3.39-15.80	(2/)	(2/)
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other	7.95	6.12-20.00	4.70	2.58-5.36

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 1998, BY METHOD OF TRANSPORTATION 1/ 2/

(Thousand metric tons)

Method of transportation	Quantity
Truck	16,000
Rail	743
Waterway	1,020
Total transported	17,800
Not transported (used at plant)	633

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 1998

		Steel slag			Iron slag	
Company	Plant location	Basic oxygen furnace	Open hearth	Electric arc furnace	Blast furnace	Slag type
Blue Circle Atlantic Inc.	Sparrows Point, MD				X	Granulated.
Buffalo Crushed Stone, Inc.	Buffalo, NY	X			X	Air cooled.
C.J. Langenfelder & Sons, Inc.	Baltimore, MD	X				
Do.	Braddock, PA	X				
Heckett MultiServ Co.	Armorel, AR			X		
Do.	Fontana, CA			X	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.	Canton, OH			X		
Do.	Mansfield, OH	X				
Do.	Massillon, OH			X		
Do. (Warren Plant)	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.
International Mill Services, Inc.	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		
Do.	Charlotte, NC			X		
Do.	Perth Amboy, NJ			X		
Do.	Riverton, NJ			X		
Do.	Auburn, NY			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.	Reading, PA	X		X		
International Mill Service	Pricedale, PA	X		X		
Do.	Darlington. SC	X		X		

TABLE 8--Continued
PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1998

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 Services, Inc.--Continued	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		
Holnam Inc.	Gary, IN				X	Air cooled, granulated, and expanded.
Do.	Weirton, WV				X	Granulated.
Lafarge Corp.	Granite City, IL	X				Air cooled.
Do.	Cleveland, OH				X	Do.
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.	Beaver, PA				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.
Marietta Materials, Inc.	Raleigh, NC	X			X	Do.
Olympic Mill Services	Sequin, TX			X		
Stein, Inc.	Decatur, AL	X				
Do.	Cleveland, OH	X			X	
Do.	Lorain, OH					Air cooled.
Vulcan Materials Co.	Alabama City, AL				X	Do.
Do.	Fairfield, AL	X			X	Do.
IMS Waylite Corp.	Bethlehem, PA	X	X		X	Air cooled and expanded.
Do.	Cambria, PA		X	X		Air cooled.