# **SLAG—IRON AND STEEL**

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

Slags are nonmetallic coproducts of many metallurgical processes and consist primarily of calcium, magnesium, and aluminum silicates. Iron and steel slags are coproducts of iron and steel production.

In the blast furnace production of iron, the furnace is charged with iron ore, fluxing agents, and coke as fuel and reducing agent; the iron ore is a mixture of iron oxides, silica, and alumina, and the fluxing agents are usually limestone and/or dolomite. Oxygen in the preheated air blown into the furnace reacts with the carbon of the coke to generate the additional heat and carbon monoxide. The iron oxide in the ore is reduced to iron by the carbon monoxide to yield carbon dioxide and metallic iron. The fluxing agents dissociate into calcium and magnesium oxides and carbon dioxide. The oxides of calcium and magnesium combine with and remove impurities, such as silica and alumina, in the ore to form slag. The distance between the furnace and the cooling pit determines whether the slag shall be transported directly or by means of iron ladles. Cooling rates, which can be controlled, and chemical composition affect the physical properties of the slag, such as density, porosity, and particle size. Depending on the cooling method, three types of iron slag can be produced: air cooled, expanded, and granulated.

Allowing the molten slag to cool slowly in an open pit produces air-cooled slag. When the material solidifies under slow cooling conditions, escaping gases leave behind a porous, low-density aggregate. Upon faster cooling, the slag tends to be hard and dense, which makes it especially suitable for use in road base and similar structural applications. Upon crushing and screening, slag attains a prismatic shape and a rough surface texture with a high coefficient of friction and good adhesion to bituminous and cement binders, a low coefficient of thermal expansion, and good fire resistance. These characteristics give it the best resistance of all road aggregates to stripping of the binder caused by the combined action of water and traffic.

Expanded slag is formed by rapid cooling of molten slag in water or in water combined with steam and compressed air. The presence of steam and other gases enhance the porosity and vesicular nature of the slag, should result in a lightweight aggregate suitable for use in concrete.

Granulated slag is produced by quenching the molten slag with water jets. Quenching prevents the crystallization of minerals that constitute 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 character.

Slags are also coproducts of steelmaking processes. Production of steel requires the removal of excess silicon by mineralization, using added lime, and carbon, by oxidation from pig iron. Steel slag is a hard, dense material somewhat similar to air-cooled iron slag. The high density and high hardness of steel slag make it particularly suitable as road aggregate.

Slag from iron and steel plants is transported to processing plants. After the removal of free metal, the slag undergoes crushing, grinding, and screening operations to meet various use specifications. Processed slag is either shipped to its buyer for immediate use or stored at the processing site.

#### **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 1999 (R.Y. Twitmyer, President, National Slag Association, oral commun., 2000). The passage of the Transportation Equity Act for the 21st Century, with its \$205 billion spending plan, by Congress in 1998, did not lead to an increase in slag consumption in 1999, but may yet have an effect during the next few years as highway construction and repairs accelerate.

#### Production

Actual iron and steel slag production data in the United States cannot be ascertained precisely because the iron and steel industry does not routinely measure slag output. Consequently, the data collected and reported by the U.S. Geological Survey represent the slag sales rather than the output. Slag outputs in iron and steel production are highly variable and depend mostly on the chemistry of the raw meal and the type of furnace. Typically, for an iron ore grading 60% to 66% iron, blast furnace slag production ranges from about 220 to 370 kilograms per metric ton of pig or crude iron produced. Lower grade ores yield higher slag fractions, sometimes as high as 1 metric ton (t) of slag per metric ton of pig iron. Steel slag outputs are approximately 20% by mass equivalent of the steel output. A good fraction of it is entrained steel, which is recovered during the processing of the slag and returned to the furnace. After removal of the entrained steel, the marketable slag weight is equivalent to about 10% to 15% of the steel output.

According to the International Iron and Steel Institute (IISI), 1999, U.S. pig iron production was 48 million metric tons (Mt) and 52 Mt in 1998 and 1999, respectively. Thus, the iron slag production was about 11 and 12 Mt in 1998 and 1999,

respectively. Similarly, U.S. steel production for 1998 and 1999 was reported to be 99.0 and 97.3 Mt, respectively. The expected steel slag production would be about 17 Mt in each year.

As with the United States, no data are available on world slag production in 1999. The IISI reported that world pig iron output was about 536 Mt and crude steel production was 786 Mt in 1999. The estimated combined iron and steel slag production from this output was approximately 200 Mt.

Tables 1 through 7 list data compiled from the survey of the processors of domestic slags. The data for 1998 and 1999 reflect a response by 95% of the slag processors queried. Where applicable, estimates have been incorporated for the non-respondents and for data omitted from the returned questionnaires. Table 8 lists the processing facilities that responded to the survey in 1999.

#### Consumption

Iron and steel slags have a wide range of uses, ranging from road construction to waste stabilization. Their uses also include cement manufacture, concrete aggregates, agriculture, glass manufacture.

Slag production and consumption rates do not correlate because time lags between production and sale of the slag to the final customer can be significant. One reason for the lag is the need for aging or "curing" 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. Furthermore, many slag producers accumulate large stockpiles to be able to participate in bids to supply large construction projects.

In 1999 air-cooled slag accounted for 47% of total ferrous shipments in the United States (table 1). The total U.S. sales of domestically produced air-cooled blast furnace slag, about 9.0 Mt, worth more than \$58 million, recorded a14% decrease in tonnage but only an 8% loss in revenues in 1999 compared with 10.3 Mt production and \$63.2 million sales. Expanded and granulated slag sales remained unchanged at 1.9 Mt. The revenue decreases shown in table 1 were due to decrease in unit prices as listed in table 2. Total slag revenues for 1999 were \$153 million;, which was a modest 2.0% gain over the revenues in 1998. The Mid-Atlantic Region, which edged out the North-Central Region, accounted for more than 47% of total revenues for the country. The North-Central region was a close second with 45% of revenues (table 3).

In 1999, sales for asphaltic concrete aggregates, concrete aggregates, fill, and road bases accounted for 72% of the total revenues from air-cooled blast furnace slags in the United States (table 4). Other uses were for soil conditioning, sewage treatment, and mineral wool production. Road bases, which largest use of steel slag was for, accounted for 36% of the total, followed by asphaltic concrete aggregates (25%) and fill (15%) (table 5). Unit prices for slags, which showed a wide range of values, depended on their use categories (table 6).

#### Transportation

Most of the 18.3 Mt of iron and steel slag was transported by truck; rail and barge transportation accounted for only 12% of the total (table 7). Because most slag was transported less than 100 kilometers, trucks were the most economical means of transportation.

#### **Foreign Trade**

Imports account for 5% per year of total slag consumption in the United States. Several cement companies-notably Lafarge Corp., Lonestar Industries, Inc., and Blue Circle Cement Company, import and grind granular blast furnace slag. Brokers also import appreciable quantities of slag on behalf of consumers of slags. Total imports were slightly less than 1 Mt in 1999. The major sources of imports were France (37%), Brazil (10%), The United Kingdom (9%), Italy (8%), and Canada (6%).

#### **Current Research and Technology**

Slag processing is a high-tonnage and low-value industry that readily sells all the slag it handles. Therefore, the industry seldom feels the need for technical innovations. Recently, however, some improvements have been made in slag granulation systems, especially in reducing the energy costs for further processing. 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 grinding. It is claimed to have the advantage of reducing the pollution associated with wet granulation as it 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 some energy recovery in the form of hot water or heated air.

Recently, Texas Industries, Inc. 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 clinker kiln as part of the raw material mix. The company claimed that with use of ChemStar, clinker production could be enhanced by as much as 15% (Robert D. Rogers, President, Texas Industries, oral commun., 1998).

#### Outlook

Construction on Nucor Corporation's new 1-million-ton-peryear electric arc furnace steel mill to produce steel plate in Hertfort, NC, is proceeding according to schedule, and should start operations in the third quarter of 2000, (at URL http://www.nucor.com). When operating at full capacity, this plant is expected to produce 150,000 to 200,000 metric tons of slag annually.

Some blast furnace operations may close owing to severe competition in the iron market place. Continuing blast furnace shut downs will lead to decline in blast furnace slag supplies, which may lead to an increase in imports. An increase in the use of steel slags may be on the horizon as blast furnace slag sources decline.

Efforts to promulgate the Kyoto Protocol of 1999 on reductions of green house gases may lead to a carbon tax being levied on fossil fuels. This may force the cement industry to increase the production of blended cements, including those using slags, to reduce fuel consumption.

#### **References Cited**

International Iron and Steel Institute, 1999, STEEL statistics Yearbook: International Iron and Steel Institute, p. MM16.

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

#### GENERAL SOURCES OF INFORMATION

#### **U.S. Geological Survey Publications**

Iron and Steel. Ch. in Mineral Commodity Summaries, annual.<sup>1</sup>

Slag—Iron and Steel. Ch. in Mineral Commodity Summaries, annual.<sup>1</sup>

<sup>&</sup>lt;sup>1</sup>Prior to January 1996, published by the U.S. Bureau of Mines.

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

#### (Million metric tons and million dollars)

			Blast fur	nace slag						
	Air-c	cooled	Expan	ided 3/	To	tal	Steel	l slag	Total	l slag
Year	Quantity	Value 4/	Quantity	Value 4/	Quantity	Value 4/	Quantity	Value 4/	Quantity	Value 4/
1998	10.3	63.1	1.9	64.4	12.2	127.0	6.2	22.9	18.4	150.0
1999	8.9	58.3	1.9	62.2	10.9	120.0	8.1	32.9	19.0	153.0

1/ Data are rounded to no more than 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)

	Iı	on blast furnace	slag		
			Total	Steel	Total
Year	Air-cooled	Expanded 1/	iron slag	slag	slag
1998	6.00	34.00	10.00	4.00	8.00
1999	6.50	32.00	11.00	4.00	8.00
4/2 1 1					

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 $1\!\!/ 2\!\!/$

#### (Million metric tons and million dollars)

		1998				1999			
	Air-c	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	6.3	37.1	7.2	53.9	5.3	34.8	6.3	53.6	
Mid-Atlantic: Maryland, New York, Pennsylvania									
West Virginia	2.0	14.8	3.0	62.4	1.9	13.3	2.8	56.8	
Other 4/	2.0	11.2	2.0	11.2	1.8	10.1	1.8	10.1	
Total	10.3	63.1	12.2	127.0	8.9	58.3	10.9	120.0	

1/ Data are rounded to no more than 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 4AIR-COOLED BLAST FURNACE SLAG SOLDOR USED IN THE UNITED STATES, BY USE 1/

(Million metric tons and million dollars)

	19	98	19	99
Use	Quantity	Value 2/	Quantity	Value 2/
Asphaltic concrete aggregate	1.8	11.3	1.7	11.3
Concrete aggregate	1.3	9.0	1.2	8.6
Concrete products	0.2	1.3	0.3	1.7
Fill	1.5	8.1	1.1	5.2
Mineral wool	0.5	3.8	0.5	4.4
Railroad ballast	(3/)	0.4	0.2	0.6
Road bases	4.1	22.5	3.0	16.7
Roofing, built-up and shingles	(3/)	0.6	(3/)	0.5
Other 4/	0.8	6.0	1.0	9.3
Total	10.3	63.1	8.9	58.3

 $1/\,\textsc{Data}$  are rounded to no more than three significant digits; may not add to totals shown. Excludes imports.

2/ Value based on selling price at plant.

3/ Less than 1/2 unit.

4/ Includes cement, ice control, glass manufacture, sewage treatment, soil conditioning and miscellaneous.

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

#### (Million tons and million dollars)

	19	1998		
Use	Quantity	Value 3/	Quantity	Value 3/
Asphaltic concrete aggregate	1.1	5.6	1.6	9.0
Fill	1.4	3.4	1.5	4.2
Railroad ballast	0.2	0.5	0.3	0.9
Road bases	2.5	8.3	2.9	10.1
Other 4/	1.1	5.1	1.7	8.8
Total	6.2	22.9	8.1	32.9

1/ Data are rounded to no more than 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 1999, BY USE

#### (Dollars per metric ton)

	Iron blast	Iron blast furnace slag 1/		
Use	Average	Range	Average	Range
Asphaltic concrete aggregate	6.00	5.00-12.00	5.00	2.00-7.00
Concrete products	6.00	5.00-9.00	(2/)	(2/)
Fill	5.00	2.00-7.00	3.00	1.00-4.00
Mineral wool	7.00	3.00-10.00	W	(2/)
Railroad ballast	3.00	3.00-8.00	3.00	2.00-22.00
Road bases	5.00	2.00-9.00	3.00	1.00-11.00
Roofing, built-up and shingles	11.00	3.00-14.00	(2/)	(2/)
Other 3/	7.00	6.00-20.00	5.00	2.00-5.00

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 \$1.00 to \$30.00 per metric ton for iron steel slag. 2/ No use reported.

3/ Includes cement manufacture, glass manufacture, sewage treatment and soil conditioning.

## TABLE 7SHIPMENTS OF IRON AND STEEL SLAG IN THE UNITED STATESIN 1999, BY METHOD OF TRANSPORTATION 1/ 2/

	Quantity
	(million
Method of transportation	metric tons)
Truck	16.0
Rail	1.2
Waterway	1.0
Total	18.3
Not transported (used at plant)	0.7

1/ Data are rounded to no more than three significant digits; may not add to totals shown.

2/ Excludes imported slag.

TABLE 8
PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1999

			Steel slag			
		Basic	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	Electric		Iron slag
		oxygen	Open	arc	Blast	8
Company	Plant location	furnace	hearth	furnace	furnace	Slag type
Blue Circle Cement Co.	Baltimore, MD	X	nearth	Turnace	X	Granulated.
Buffalo Crushed Stone	Buffalo, NY	X			X	Air cooled.
C.J. Langenfelder	Baltimore, MD	X			Λ	All cooled.
Do.	Braddock, PA	X				
Edward C. Levy Co.	Detroit, MI	Х		X	Х	Air cooled and expanded.
Heckett MultiServ Co.	Armorel, AR			Х		
Do.	Fontana, CA				Х	Air cooled.
Do.	Wilton, IA			Х		
Do.	Chicago, IL			Х		
Do.	Sterling, IL			Х		
Do.	East Chicago, IN	Х				
Do.	Indiana Harbor, IN	Х				
Do.	Ashland, KY	Х			Х	Air cooled.
Do.	Coalton, KY			Х		
Do.	Newport, KY			X		
Do.	Owensboro, KY			X		
				X		
Do.	Kansas City, MO Canton, OH					
Do.		77		Х		
Do.	Mansfield, OH	X				
Do.	Massillon, OH			Х		
Do. (Warren Plant)	Warren, OH	Х				
Do.	do.			Х		
Do.	Youngstown, OH			Х		
Do.	Butler, PA			Х		
Do.	Provo, UT		Х		Х	Air cooled.
nternational Mill Services	Fort Smith, AR			Х		
Do.	Kingman, AZ			Х		
Do.	Pueblo, CO	Х				
Do.	Claymont, DE			Х		
Do.	Cartersville, GA			X		
Do.	Alton, IL			X		
				<u>л</u> Х	V	A :
Do.	Chicago, IL				Х	Air cooled.
Do.	Kankakee, IL			X		
Do.	Gary, IN			Х		
Do.	Huntington, IN			Х		
Do.	Laplace, LA			Х		
Do.	Jackson, MI			Х		
Do.	Monroe, MI			Х		
Do.	St. Paul, MN			Х		
Do.	Jackson, MS			Х		
Do.	Charlotte, NC			Х		
Do.	Perth Amboy, NJ			Х		
Do.	Riverton, NJ			Х		
Do.	Auburn, NY			X		
Do.	Hubbard, OH			X		
Do.	Marion, OH			X		
	Middletown, OH	Х		X		
Do.						
Do.	Mingo Junction, OH	X		X		
Do.	Warrent, OH			Х		
Do.	McMinnville, OR			Х		
Do.	Portland, OR			Х		
Do.	Brideville, PA			Х		
Do.	Coatesville, PA			Х		
Do.	Holsopple, PA			Х		
Do.	New Castle, PA			Х		
				X		
Do.	Midland PA					
Do.	Midland, PA Pricedale PA	x				
Do. Do. Do.	Midland, PA Pricedale, PA Reading, PA	X X		X X		

#### TABLE 8--Continued PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1999

		Steel slag				
		Basic		Electric		Iron slag
		oxygen	Open	arc	Blast	
Company	Plant location	furnace	hearth	furnace	furnace	Slag type
International Mill ServiceContinued:	Georgetown, SC	Х		Х		
Do.	Jackson, TN	Х		Х		
Do.	Beaumont, TX	Х		Х		
Do.	El Paso, TX	Х		Х		
Do.	Jewett, TX	Х		Х		
Do.	Longview, TX	Х		Х		
Do.	Midlothian, TX	Х		Х		
Do.	Plymouth, UT	Х		Х		
Do.	Seattle, WA	Х		Х		
Do.	Saukville, WI	Х		Х		
Do.	Weirton, WV	Х		Х		
Holnam Inc.	Gary, IN				Х	Air cooled, granulated,
						and expanded.
Do.	Weirton, WV				Х	Granulated.
IMS Waylite Corp.	Bethlehem, PA	Х	Х		Х	Air cooled and expanded
Do.	Cambria, PA		Х		Х	Air cooled.
Lafarge Corp.	Cuyahoga, OH		Х			Do.
Do.	Lordstown, OH		Х		Х	Granulated.
Do.	McDonald, OH		Х			
Do.	Mingo Junction, OH				Х	Air cooled.
Do.	Warren, OH				Х	Do.
Do.	Youngstown, OH		Х			
Do.	West Mifflin, PA				Х	Do.
Do.	Weirton, WV				Х	Do.
The Levy Co. Inc.	Burns Harbor, IN	Х			Х	Do.
Do.	East Chicago, IN				Х	Do.
Martin Maretta Materials	Raleigh, NC	Х			Х	Do.
Maryland Slag Co.	Baltimore, MD				Х	Do.
Olympic Mill Services	Seguin, TX			Х		
Stein, Inc.	Decatur, AL	Х				
Do.	Cleveland, OH	Х			Х	Air cooled.
Do.	Lorain, OH				Х	Do.
Vulcan Materials Co.	Alabama City, AL				Х	Do.
Do.	Fairfield, AL	Х			Х	Do.