SLAG—IRON AND STEEL

By Hendrik G. van Oss

Iron (or blast furnace) and steel slags are silicate byproducts of iron- and steelmaking, and contain most of the nonferrous components of the original ores, fluxes, reductants, and metallic feeds to the iron and steel furnaces. Steel slags in particular may also contain significant amounts of entrained (free) metal.

The appearance of slag—stony, glassy, or metallic; compact or vesicular—depends partially on overall slag chemistry and a great deal on how the material is cooled. To a major extent, the uses of slag are determined by the cooling method used.

Slag has been used for construction purposes—especially road metal—since Roman times. The dramatic expansion in Europe of iron and steel production associated with the Industrial Revolution led to a commensurate increase in slag production. By the early 19th century, slag output was rapidly outpacing consumption and there was an alarming growth of unattractive slag heaps on valuable industrial land. By the mid-19th century, research had demonstrated a number of new uses for slag, particularly as an aggregate for concrete and as a cementitious material in its own right. Consumption remained relatively modest until the 20th century, when a major new use—in asphalt blends for road paving—was developed, and became popular in step with demand for smooth roads by the growing automobile-owning public. This use, together with the rapid growth of concrete usage worldwide, led to the consumption of most existing slag heaps and a current consumption roughly apace with new slag production. The utilization of slag, therefore, is one of the great, yet relatively unsung, stories of recycling. Research is ongoing to expand and refine the uses of slag. Slag is properly recognized as a valuable coproduct of iron- and steelmaking, not a waste product.

The above notwithstanding, the iron- and steelmakers generally contract with other companies to process the slag and to haul it away for sale. Although the arrangements vary, these contracts generally are long term. Commonly, the molten slag is supplied to the processor-hauler gratis, with some modest percentage of the eventual sale revenues returned to the mill. Or, certain high-iron slags may be separated and returned as furnace feed. In the case of steel slags, the valuable entrained steel is recovered by the processor and returned, at below scrap prices, to the steel mill. However, the major processing is simply the controlled cooling of the molten slag at or near the mill and subsequent crushing and screening.

There are three main types of blast furnace slag. Air-cooled blast furnace slag, the least expensive form, is allowed to solidify relatively slowly in ladles or in pits. Final cooling can be accelerated with a water spray. The cooled material is hard and dense. After crushing and screening, it is used mainly for road metal and bases, asphalt paving, railway ballast, and concrete aggregate. Expanded or foamed slag is cooled through a water jet, which leads to rapid steam generation and the development in the slag of innumerable vesicles. This material binds well with cement and is used mainly as aggregate for lightweight concrete. Granulated slag is cooled rapidly (quenched) with water to form a granular glass. Although it can be used as an aggregate, it commonly is used as a pozzolan—a material that, in the presence of free lime and water, develops cementitious properties. To this end it can be used to make cement (slag cement) or, more commonly, is ground and mixed with portland cement to make portland slag (blended) cement. Blended cement and slag cements are particularly popular outside the North American market. Granulated slag can also be used as a liming agent—such as for soil conditioning.

A fourth product made from blast furnace slag is mineral wool. Cooled slag for this purpose is remelted and poured through an air stream or jet of dried steam or other gas, 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 fibers, which are collected mechanically and layered. The material has excellent thermal insulation properties.

Steel slag is a hard, dense material similar to air-cooled iron slag, and is particularly suitable for road making.

The data shown in tables 1 through 7 in this report were compiled from surveys of domestic slag processing facilities conducted by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS).[1] The data for 1994 reflect a voluntary response by 88 of 93 operations canvassed, and that for 1995 a response by all 87 operations queried. Where applicable, estimates have been incorporated for data omitted from returned questionnaires. Owing to the nature of slag and its generally low unit value, precise weighing and handling of shipments is not a universal practice in the industry. The tabulated data, administratively rounded to three significant figures, should be viewed accordingly. Table 8 lists the facilities that responded to the 1995 survey.

As shown in table 1, total sales of domestically produced iron and steel slag increased by about 4.5% by mass in 1995 over those in 1994. Revenues were reported as $144 million, up 3%. Blast furnace slag accounted for 66% of the total ferrous slag tonnage sold and 85% of the value. The steel slag contribution to value was modest, but is misleading as it does not include the value of entrained steel within the slag. This material routinely is recovered and returned to the mill, but data on this are unavailable. Ferrous slags were processed in 30 States—blast furnace slag in 12 and steel slag in 29.

Legislation and Government Programs

In recent years, legislative issues of concern to the slag industry have included various proposals at State and Federal levels to classify slags as waste, under various categories. The industry has been largely successful at keeping slag from being so defined, citing slag's relative chemical inertness and its marketability. Legislatively, 1995 was a quiet year. The only significant action was in South Carolina where, in the process of permitting a landfill that contained (unrelated) baghouse dust from a local electric arc furnace steel mill, the State ruled that steel slag in an old dump on the property was solid waste. The ruling, unsuccessfully appealed by the company, did not impact the company's ability to market the material in the dump, nor did it apply to slag—such as that from current operations—not contained in the dump.

Production

There are no data for actual U.S. ferrous slag production because the iron and steel industry does not routinely measure slag output. The USBM/USGS surveys of the slag industry query sales, not production, of slag. For metallurgical purposes, theoretical slag output may be calculated for an individual furnace heat based on the chemical composition of the raw material charge. The amount of iron slag produced by a blast furnace depends to a large extent on the overall chemistry of the raw material charge—this is governed mainly by the grade of the iron ore. Typically, for an ore feed grading in the range of 60% to 66% iron, blast furnace slag production is about 250 to 300 kilograms per metric ton of crude (pig) iron obtained. Lower grade ore yields more slag—sometimes as high as 1.0 to 1.2 tons of slag per ton of pig iron.

Steel slag output also is highly variable, being dependent on feed chemistry and the type of furnace used. Molten steel slag output typically is about 20%, by mass, of the steel output. Commonly, about one-half of this mass is entrained steel—material that generally is recovered and returned to the furnace. The marketable slag after entrained steel removal typically is in the range of 10% to 15% of the steel output. Some of this material, too, may be returned to the furnace.

According to International Iron and Steel Institute (IISI) data, U.S. pig iron production was about 49.4 million tons and 50.9 million tons in 1994 and 1995, respectively. It may thus be estimated that blast furnace slag production in both years was on the order of 12 to 15 million tons. Likewise, U.S. steel production for 1994 and 1995 was about 91.3 million tons and 95.2 million tons, respectively, and steel slag output can be estimated in the range of 9 to 14 million tons for each year. As with the United States, there are few data on world slag production. According to provisional data by IISI, world pig iron output totaled about 526 million tons in 1995, and crude steel output totaled about 748 million tons. It can be roughly estimated that world ferrous slag accompaniment to this production totaled at least 250 million tons.

Consumption

Although slag production and availability are proportional to iron and steel output, the correlation of slag sales and smelter output is not necessarily strong. There can be a significant time lag between production and sales to final customers. One reason for this is that fresh slag, particularly from steel furnaces, contains free lime which can adversely affect any concrete made from it. Generally, slag will be stored in dumps to “cure” for 6 months or more to reduce the lime content to acceptable levels. The curing will also allow for any expansion of dicalcium silicate (C_2S in industry shorthand) in the slag. Another reason is that slag processors commonly will seek to accumulate stockpiles so as to be better positioned to bid to supply slag to large construction projects. Unlike sales of iron and steel themselves, the slag market usually depends on very local (construction) demand. Except for some regions having serious shortages of natural aggregates—the main competitor for slag—it generally is not economic to transport slag much more than about 65 kilometers from the plant. Accordingly, within limits of slag availability, sales of slag (to final customers) from a given smelter can vary independently of iron and steel output.

As shown in table 1, total U.S. sales of domestically produced blast furnace slag rose about 12%, by mass, in 1995 over those in 1994. This increase was significantly higher than the 3% increase in pig iron production noted above and included significant sales of stockpiled material. However, as shown in table 2, this performance was mitigated by lower prices and, overall, blast furnace slag sales revenues increased only 7%. Most of the sales were of air-cooled slag. The North Central region (see table 3) showed the largest blast furnace slag sales and sales increases.

Overall, the tonnage sales increases reflected a strong construction market nationwide. The lackluster sales prices were in part due to strong competition from natural aggregates. Perhaps more important, according to the National Slag Association, was a push by the iron and steel mills to force the slag processors to reduce slag stockpiles at the smelters. This was for environmental reasons—the stockpiles were unsightly and vulnerable to future adverse environmental legislation.

As shown in tables 1 and 2, steel slag sales fared poorly in 1995, falling 8% by tonnage and 16% in revenues. This was mainly due to competition from natural aggregates and from blast furnace slag. Because of the lime problem, there also was resistance to sales of uncured steel slag stockpile material.

The major uses of blast furnace and steel slags in the United States are shown in tables 4 and 5. The dominant uses of air-cooled blast furnace slag continued to be for aggregate, much of it related to general road making and concrete. Elsewhere in the world there is a similar mix of uses, with a significant exception of greater overseas use of slag for cement (both as kiln feed and for blended cements). Slag industry data for 1995 on U.S. sales destined for cement are proprietary, but the amount is very small. Nonproprietary slag consumption (perhaps including imports) data from U.S. cement manufacturers show a decline from about 150,000 tons in 1990 to an estimated 30,000 tons in

1995. However, the decline may not be real in that there has been an increasing practice by concrete producers to cut costs by blending their own portland slag cements rather than purchasing the same from the cement industry. Data on this were not available. Prices for slag, as shown in table 6, varied by type of use. The price ranges shown are averages reported by different companies.

Transportation

Table 7 depicts the tonnages of slag transported, by method. As in previous years, the vast majority of slag was transported by truck. Most truck transport was to destinations within 65 kilometers of the plant. Reported rail and waterway destinations were much farther afield (up to 1,000 kilometers).

Foreign Trade

Data from the Bureau of Census concerning slag imports in 1995 contained a number of unresolved discrepancies. The data appear to show granulated slag imports totaling about 220,000 tons—about 10% higher than in 1994—with the major suppliers, as in 1994, being Canada and South Africa. Exports of slag were believed to be similar to the levels in 1994—about 4,000 tons.

Outlook

Barring the enactment of burdensome environmental restrictions on slag, a significant market for ferrous slag in the construction sector seems secure for the foreseeable future. Market growth for slag would appear to hinge on general construction trends, the regional availability of competing (natural) aggregates and pozzolans, and the outcome of research to widen the range of uses for slag. In the long term, overall availability of domestic blast furnace slag likely will decline as stocks are consumed and as existing blast furnaces become uneconomic and are shut down. It is unclear if current iron slag consumption levels would be maintained through increased imports. And there seems little prospect for the construction of new blast furnaces in the United States. The long-term supply of steel slag is more secure, and within its (currently) more restricted range of uses, consumption of steel slag could increase as blast furnace slag availability declines.

[1]Minerals information activities of the former U.S. Bureau of Mines were transferred to the U.S. Geological Survey in Jan. 1996.

OTHER SOURCES OF INFORMATION

National Slag Association
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Wayne, PA 19087-4043
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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/
1994	10,700	62,400	1,600	51,100	12,300	114,000	7,800	26,900	20,100	140,000
1995	12,000	68,200	1,810	53,700	13,800	122,000	7,160	22,600	21,000	144,000

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
1994	5.84	31.85	9.23	3.45	6.99
1995	5.68	29.73	8.82	3.16	6.89

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)

Region and State	1994				1995			
	Air-cooled, screened and unscreened		Total, all types		Air-cooled, screened and unscreened		Total, all types	
	Quantity	Value 3/	Quantity	Value 3/	Quantity	Value 3/	Quantity	Value 3/
North Central:								
Illinois, Indiana, Michigan, Ohio	6,960 r/	40,600	7,600	54,800	7,960	44,300	8,800	60,100
Middle Atlantic:								
Maryland, New York, West Virginia, Pennsylvania	2,040	13,800 r/	3,000	50,700	2,200	15,100	3,160	52,900
Other 4/	1,700 r/	8,090 r/	1,700	8,090	1,860	8,860	1,860	8,860
Total	10,700	62,400	12,300	114,000	12,000	68,200	13,800	122,000

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 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)

	1994		1995	
Use	Quantity	Value 2/	Quantity	Value 2/
Asphaltic concrete aggregate	1,940	12,200	1,920	11,700
Concrete aggregate	1,180	8,540	1,140	8,360
Concrete products	498	3,120	327	2,190
Fill	870	3,030	1,340	4,010
Glass manufacture	W	W	W	W
Mineral wool	621	4,430	647	4,420
Railroad ballast	188	867	108	569
Road bases	4,850	26,500	5,470	30,700
Roofing, built-up and shingles	71	946	63	589
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other 3/	475	2,800	997	5,650
Total	10,700	62,400	12,000	68,200

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)

	1994		1995	
Use	Quantity	Value 3/	Quantity	Value 3/
Asphaltic concrete aggregate	1,140	5,000	1,040	4,800
Fill	1,320	3,750	1,380	3,660
Railroad ballast	160	467	168	553
Road bases	3,170	11,300	2,820	7,940
Other 4/	2,000	6,400	1,760	5,630
Total	7,800	26,900	7,160	22,600

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 1995, BY USE

(Dollars per metric ton)

	Iron blast furnace slag 1/		Steel slag	
Use	Average	Range	Average	Range
Asphaltic concrete aggregate	6.10	4.60 - 11.80	4.60	2.40 - 6.70
Cement manufacture	W	W	W	W
Concrete products	6.70	W	(2/)	(2/)
Fill	3.00	.30 - 6.80	2.70	1.40 - 4.40
Glass manufacture	W	W	W	W
Mineral wool	6.80	2.80 - 9.00	W	(2/)
Railroad ballast	5.30	4.00 - 7.00	3.30	1.90 - 40.50
Road bases	5.60	2.70 - 7.70	2.80	.90 - 4.40
Roofing, built-up and shingles	9.40	5.50 - 15.00	(2/)	(2/)
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other	5.70	2.20 - 15.00	3.20	.50 - 5.40

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 $45.00 per ton.
2/ No use reported.

TABLE 7
SHIPMENTS OF IRON AND STEEL SLAG IN THE UNITED STATES
IN 1995, BY METHOD OF TRANSPORTATION 1/ 2/

Method of transportation	Quantity (thousand metric tons)
Truck	17,600
Waterway	926
Rail	973
Total transported	19,500
Not transported (used at plant)	1,510

1/ Data are rounded to 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 1995

		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.
Alexander Mill Service	Blytheville, AR			X		--
Do.	Kankakee, IL			X		--
Do.	Charlotte, NC			X		--
Do.	Holsopple, PA			X		--
Do.	Washington, PA			X		--
Do.	Cayce, SC			X		--
Do.	Darlington, SC			X		--
Do.	Seguin, TX			X		--
Do.	Plymouth, UT			X		--
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				--
Dunbar Slag Co. Inc.	Wheatland, PA	X		X		Do.
Heckett Multiserv Co.	Fontana, CA				X	Do.
Do.	Wilton, IA			X		--
Do.	Chicago, IL				X	Air-cooled.
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. (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.	Pueblo, CO	X				--
Do.	Claymont, DE			X		--
Do.	Tampa, FL			X		--
Do.	Cartersville, GA			X		--
Do.	Alton, 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		--

TABLE 8--Continued
PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1995

Company	Plant location	Steel slag			Iron slag	
		Basic oxygen furnace	Open hearth	Electric arc furnace	Blast furnace	Slag type
International Mill Service--Continued	Monroe, MI			X		--
Do.	St. Paul, MN			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.	Burgettstown, PA			X		--
Do.	Coatesville, PA			X		--
Do.	Midland, PA			X		--
Do.	Pricedale, PA	X		X		--
Do.	Reading, PA	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.	Saukville, WI	X		X		--
Do.	Weirton, WV	X		X		--
Koch Minerals	Gary, IN				X	Air-cooled, expanded and granulated.
Do.	Weirton, WV				X	Granulated.
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.
Standard LaFarge Co.	Granite City, IL				X	Do.
Do.	Cleveland, OH				X	Air-cooled and expanded.
Do.	Cuyahoga, OH		X			--
Do.	Lordstown, OH		X			Granulated.
Do.	McDonald, OH		X			--
Do.	Mingo Junction, OH				X	Air-cooled.
Do.	Warren, OH				X	Do.
Do.	Youngstown, OH		X			--
Do.	Penn Hills, PA		X			--
Do.	West Aliquippa, PA				X	--
Do. (Brown Reserve)	West Mifflin, PA				X	Air-cooled.
Do. (Duquesne)	do.	X	X		X	Do.
Do.	Weirton, WV				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.