Slag

Iron-Blast-Furnace

By William R. Barton and Perry G. Cotter

PRODUCTION of 86 million tons of pig iron in 1964 yielded an estimated 30 million tons of iron-blast-furnace slag. Of this amount, 90 percent was supplied to slag processors. Output of processed slag increased more than 13 percent in tonnage and 12 percent in value in 1964.

TABLE 1.—Iron-blast-furnace slag processed in the United States by types (Thousand short tons and thousand dollars)

<table>
<thead>
<tr>
<th>Year</th>
<th>Air-cooled</th>
<th>Granulated</th>
<th>Expanded</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Screened Value</td>
<td>Unscreened Quantity</td>
<td>Value</td>
<td>Screened Value</td>
</tr>
<tr>
<td>1955-59 (average)</td>
<td>28,640 $37,122</td>
<td>1,505 $1,083</td>
<td>3,805 $1,529</td>
<td>2,924 $8,313</td>
</tr>
<tr>
<td>1960</td>
<td>21,908 37,671</td>
<td>1,257 1,049</td>
<td>3,027 1,459</td>
<td>2,626 7,773</td>
</tr>
<tr>
<td>1961</td>
<td>19,250 33,906</td>
<td>1,493 985</td>
<td>2,663 1,387</td>
<td>2,275 6,896</td>
</tr>
<tr>
<td>1962</td>
<td>18,496 32,690</td>
<td>312 340</td>
<td>2,385 1,258</td>
<td>2,249 6,615</td>
</tr>
<tr>
<td>1963</td>
<td>18,296 32,408</td>
<td>609 624</td>
<td>2,481 1,663</td>
<td>2,331 7,703</td>
</tr>
<tr>
<td>1964</td>
<td>20,009 36,438</td>
<td>621 599</td>
<td>2,840 2,170</td>
<td>2,436 7,278</td>
</tr>
</tbody>
</table>

1 Excludes value of slag used for manufacturing hydraulic cement.

Source: National Slag Association.

DOMESTIC PRODUCTION

Thirty-eight companies, 1 more than in 1963, reported operation of 60 air-cooled, 20 expanded, and 14 granulated slag plants at which 27 million tons of slag was processed.

Slag-encrusted iron reclaimed magnetically by slag processors for remelting amounted to 504,962 tons compared with 403,953 tons in 1963.

The industry's 1,678 plant and yard employees worked a total of 3,828,640 man-hours in 1964 without a disabling injury. Production per man-hour was 7.01 tons compared with 6.66 tons in 1963.

1 Commodity specialist, Division of Minerals.
2 Former commodity specialist, Division of Minerals (now retired).
TABLE 2.—Iron-blast-furnace slag processed in the United States, by States
(Thousand short tons and thousand dollars)

<table>
<thead>
<tr>
<th>Year and State</th>
<th>Screened air-cooled</th>
<th>All types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>Value</td>
</tr>
<tr>
<td>1963:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alabama</td>
<td>1,911</td>
<td>$3,853</td>
</tr>
<tr>
<td>Indiana</td>
<td>2,473</td>
<td>3,169</td>
</tr>
<tr>
<td>Illinois</td>
<td>3,460</td>
<td>6,554</td>
</tr>
<tr>
<td>Ohio</td>
<td>4,998</td>
<td>8,830</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>5,750</td>
<td>10,025</td>
</tr>
<tr>
<td>Other States</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>18,290</td>
<td>32,408</td>
</tr>
<tr>
<td>1964:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ohio</td>
<td>3,380</td>
<td>7,374</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>4,805</td>
<td>9,069</td>
</tr>
<tr>
<td>Illinois</td>
<td>5,611</td>
<td>8,809</td>
</tr>
<tr>
<td>Indiana</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Michigan</td>
<td>6,673</td>
<td>11,306</td>
</tr>
<tr>
<td>Other States</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20,569</td>
<td>38,458</td>
</tr>
</tbody>
</table>

1 Alabama, California, Colorado (1964), Kentucky, Maryland, Michigan (1963), Minnesota, New Jersey (1963), New York, Tennessee (1963), Texas, Utah (1964), and West Virginia.

Source: National Slag Association.

TABLE 3.—Shipments of iron-blast-furnace slag in the United States, by method of transportation

<table>
<thead>
<tr>
<th>Method of transportation</th>
<th>1963</th>
<th>1964</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thousand short tons</td>
<td>Percent of total</td>
</tr>
<tr>
<td>Rail</td>
<td>6,630</td>
<td>28</td>
</tr>
<tr>
<td>Truck</td>
<td>16,259</td>
<td>69</td>
</tr>
<tr>
<td>Waterway</td>
<td>576</td>
<td>2</td>
</tr>
<tr>
<td>Total shipments</td>
<td>23,465</td>
<td>99</td>
</tr>
<tr>
<td>Interplant handling</td>
<td>226</td>
<td>1</td>
</tr>
<tr>
<td>Total processed</td>
<td>23,691</td>
<td>100</td>
</tr>
</tbody>
</table>

1 Confined mainly to granulated slag used in manufacturing cement.

Source: National Slag Association.

CONSUMPTION AND USES

Use of screened air-cooled slag for aggregate, railroad ballast, mineral wool, and roofing increased substantially in 1964, but less was used for agriculture and sewage trickling media.

Unscreened air-cooled slag use in highway and airport construction was 152 percent greater in volume than in 1963, and for all uses increased 11 percent.

Cement manufacture accounted for 32 percent of the total 2.8 million tons of granulated slag sold or used by processors in 1964. Slag used for base, subbase, or fill, in road or highway construction, comprised 53 percent of the total, compared with 41 percent in 1963.

Ninety-eight percent of the expanded slag produced was used as aggregate for concrete block manufacture.
TABLE 4.—Air-cooled iron-blast-furnace slag sold or used by processors in the United States, by uses
(Thousands short tons and thousand dollars)

<table>
<thead>
<tr>
<th>Year and use</th>
<th>Screened</th>
<th></th>
<th>Unscreened</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>Value</td>
<td>Quantity</td>
<td>Value</td>
</tr>
<tr>
<td>1963:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate in—</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland cement concrete construction</td>
<td>2,662</td>
<td>$4,969</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bituminous construction (all types)</td>
<td>2,099</td>
<td>5,389</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highway and airport construction 1</td>
<td>7,013</td>
<td>12,055</td>
<td>235</td>
<td>$222</td>
</tr>
<tr>
<td>Manufacture of concrete block</td>
<td>438</td>
<td>780</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Railroad ballast</td>
<td>3,663</td>
<td>3,686</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral wool</td>
<td>473</td>
<td>792</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roofing slag—</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover material</td>
<td>348</td>
<td>1,085</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granules</td>
<td>26</td>
<td>155</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewage trickling filter medium</td>
<td>147</td>
<td>287</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural slag, liming</td>
<td>18</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other uses</td>
<td>973</td>
<td>1,069</td>
<td>454</td>
<td>372</td>
</tr>
<tr>
<td>Total</td>
<td>18,290</td>
<td>32,408</td>
<td>689</td>
<td>624</td>
</tr>
<tr>
<td>1964:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate in—</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland cement concrete construction</td>
<td>3,254</td>
<td>5,325</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bituminous construction (all types)</td>
<td>3,451</td>
<td>6,320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highway and airport construction 1</td>
<td>8,345</td>
<td>14,604</td>
<td>592</td>
<td>579</td>
</tr>
<tr>
<td>Manufacture of concrete block</td>
<td>588</td>
<td>1,063</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Railroad ballast</td>
<td>3,211</td>
<td>4,045</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral wool</td>
<td>479</td>
<td>865</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roofing slag—</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover material</td>
<td>361</td>
<td>1,112</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granules</td>
<td>43</td>
<td>233</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewage trickling filter medium</td>
<td>83</td>
<td>146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural slag, liming</td>
<td>4</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other uses</td>
<td>1,147</td>
<td>1,896</td>
<td>29</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>20,969</td>
<td>36,458</td>
<td>621</td>
<td>599</td>
</tr>
</tbody>
</table>

1 Other than in portland cement concrete and bituminous construction.

Source: National Slag Association.

TABLE 5.—Granulated and expanded iron-blast-furnace slag sold or used by processors in the United States, by uses
(Thousands short tons and thousand dollars)

<table>
<thead>
<tr>
<th>Use</th>
<th>1963</th>
<th></th>
<th>1964</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Granulated</td>
<td>Expanded</td>
<td>Granulated</td>
<td>Expanded</td>
</tr>
<tr>
<td></td>
<td>Quantity</td>
<td>Value</td>
<td>Quantity</td>
<td>Value</td>
</tr>
<tr>
<td>Highway construction (base and subgrade)</td>
<td>745</td>
<td>$1,000</td>
<td>1,176</td>
<td>$1,426</td>
</tr>
<tr>
<td>Fill (road, etc.)</td>
<td>278</td>
<td>268</td>
<td>322</td>
<td>217</td>
</tr>
<tr>
<td>Agricultural slag, liming</td>
<td>61</td>
<td>86</td>
<td>57</td>
<td>98</td>
</tr>
<tr>
<td>Manufacture of hydraulic cement</td>
<td>1,041</td>
<td>NA</td>
<td>905</td>
<td>NA</td>
</tr>
<tr>
<td>Aggregate for concrete block manufacture</td>
<td>160</td>
<td>162</td>
<td>2,206</td>
<td>$6,552</td>
</tr>
<tr>
<td>Aggregate in lightweight concrete</td>
<td>196</td>
<td>283</td>
<td>2,371</td>
<td>$7,083</td>
</tr>
<tr>
<td>Other uses</td>
<td>131</td>
<td>147</td>
<td>151</td>
<td>146</td>
</tr>
<tr>
<td>Total</td>
<td>2,461</td>
<td>1,663</td>
<td>2,251</td>
<td>6,703</td>
</tr>
</tbody>
</table>

NA—Not available.

1 Excludes manufacture of hydraulic cement, value not available.

Source: National Slag Association.
PRICES

The average value for the total slag produced was $1.73 per ton, a decrease of $0.02 per ton compared with 1963. However, because slag with diverse characteristics is produced for a variety of uses, values ranged from $0.67 per ton for material which received little processing to $5.83 per ton for smaller quantities of slag which required a high degree of screening, sizing, and washing to meet rigid specifications.

Prices for crushed slag (air-cooled, screened) used as aggregate are published regularly for 11 major U.S. cities in Engineering News-Record. At yearend, 1¼-inch slag sold for an average $2.37 per ton and ¾-inch slag sold for an average of $2.38 per ton. For the 11 cities where slag prices were quoted, highest prices were in Atlanta and lowest prices in New Orleans and Birmingham, followed closely by Pittsburgh and St. Louis.

TABLE 6.—Average value of iron-blast-furnace slag sold or used by processors in the United States, by uses

(Per short ton)

<table>
<thead>
<tr>
<th>Use</th>
<th>Air-cooled</th>
<th>Granulated</th>
<th>Expanded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate in—</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland cement concrete construction...</td>
<td>$1.87</td>
<td>$1.82</td>
<td>1.90</td>
</tr>
<tr>
<td>Bituminous construction (all types)</td>
<td>1.90</td>
<td>1.83</td>
<td>1.79</td>
</tr>
<tr>
<td>Highway and airport construction 1</td>
<td>1.79</td>
<td>1.75</td>
<td>1.79</td>
</tr>
<tr>
<td>Manufacture of concrete block...</td>
<td>1.79</td>
<td>1.75</td>
<td>1.36</td>
</tr>
<tr>
<td>Railroad ballast...</td>
<td>1.95</td>
<td>1.80</td>
<td>1.95</td>
</tr>
<tr>
<td>Mineral wool...</td>
<td>5.95</td>
<td>5.83</td>
<td>5.95</td>
</tr>
<tr>
<td>Roofing slag—</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover material...</td>
<td>3.07</td>
<td>3.08</td>
<td>3.07</td>
</tr>
<tr>
<td>Granules...</td>
<td>5.95</td>
<td>5.83</td>
<td>5.95</td>
</tr>
<tr>
<td>Sewage trickling filter medium...</td>
<td>1.95</td>
<td>1.76</td>
<td>1.95</td>
</tr>
<tr>
<td>Agricultural slag, liming...</td>
<td>1.64</td>
<td>1.80</td>
<td>1.64</td>
</tr>
<tr>
<td>Fill (road, etc.)...</td>
<td>2.02</td>
<td>1.65</td>
<td>.82</td>
</tr>
<tr>
<td>Other uses...</td>
<td>2.02</td>
<td>1.65</td>
<td>.82</td>
</tr>
</tbody>
</table>

1 Other than in portland cement and bituminous construction.
2 Base and subgrade material.

Source: National Slag Association.

TECHNOLOGY

The various methods for producing ball, granulated, foamed, and wool slag to be used in cements, bricks, glass, and soil additives were reviewed. Slags and the additives to make these various types or convert one to the other were discussed.²

Subjects discussed at the 20th Annual Meeting of the Pennsylvania Slag Association were antiskid materials, skid resistance tests, slurry seals for pavements, and the use of open hearth slag as aggregate.⁴

The manufacturing process used in making slag cements, optimum compositions of slag glasses, hydration of slag cements, and properties were reported.\(^5\)

Three hundred thousand tons of granulated blast furnace were used by the Cook County, Ill., Highway Department in the construction of an embankment for an elevated section of the Southwest Expressway.\(^6\)

The methods and equipment used to prepare bituminous road mix at the largest blast-furnace slag processing unit in Great Britain were described.\(^7\)

The National Building Research Institute of Pretoria, South Africa, found that supposedly high-magnesia blast-furnace slag could be used for construction. Two mixtures were prepared. One an interground mixture of granulated slag and portland cement clinker, and the other was a finely ground granulated slag that was mixed with portland cement in a concrete mixer on the job. About 350,000 tons of granulated slag was converted to cement by this method and supplied 12 percent of the country's cement requirement.\(^8\)

Studies were made to gain more information on the devitrification and crystallization of molten blast-furnace slag, and the mechanism and hydraulic properties of slag when mixed with portland cement. It was found that when stony or vitreous slags were heated to 800°–900° C., devitrification took place, and the heat evolved during devitrification could be measured by DTA apparatus.\(^9\)

Further evidence was presented to support the theory that the foamability of blast-furnace slag was governed by the evolution of sulfur-bearing gases, notably hydrogen sulfide.\(^10\)

The Russian Bureau of the Academy of Building and Architecture developed a method for forming housing panels of blast-furnace slag and fly ash. The technology was based upon autoclaving mixtures of foamed slag, waste fly ash from powerplants, unslaked lime, gypsum, silica sand, and portland cement. An aqueous suspension of aluminum powder was introduced in the mix as a foaming agent. Mass construction of large panelled residential blocks using external wall panels of the autoclaved aerated slag-ash concrete was accomplished.\(^11\)

In a method for melting nonumber glass batches so as to reduce the seed level in the glass product, 0.1 to 6.5 percent of blast-furnace slag

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was added to the usual mix and the batch melted at 2,600° to 2,950° F. The small quantity of slag used did not seriously discolor the glass.\textsuperscript{12}

In an improved method for preparing a stable and readily pumpable concrete in which foamed blast-furnace slag was used, the voids in the aggregate were evacuated under vacuum and then filled with water before the cementitious mix was introduced into the batch.\textsuperscript{13}

In the production of a composite expanded shale-blast-furnace slag lightweight aggregate, raw shale and slag were blended to form a mixture consisting essentially of about 42 percent silica, 18 percent alumina, 4 percent trace elements, 6 percent magnesia, and 30 percent lime. The mixture was treated with sodium sulfate or other granular inorganic foaming agent while being passed in a thin stream through a furnace heated to a high enough temperature to fuse and foam the material, ordinarily about 2,450° F.\textsuperscript{14}

The results of thermodynamic interpretations of available data on the distribution of sulfur and manganese between liquid pig iron and blast-furnace slags were reported. Special emphasis was given to the role of side reactions and the critical analysis of recent interpretations based on the thermodynamic treatment of slags as ionic solutions.\textsuperscript{15}

The correlation between the distribution of sulfur, silicon, and manganese in bath and slag under carbon monoxide partial pressure was investigated.\textsuperscript{16}

Tests were applied to mixtures of ground cement clinker and blast-furnace slag of different chemical compositions. The results showed that blast-furnace slag combines with the free lime liberated during the hydration of cement and that only in mixtures of low clinker content is there complete removal of lime, even after prolonged reaction. The maximum lime-fixation capacity of the slag was found to be approximately 5 percent by weight of the mixture liberated from the clinker in a 30 clinker-70 slag mixture.\textsuperscript{17}

\textsuperscript{13}Albert, R. J. Method of Pumping Concrete Containing Porous Aggregates. U.S. Pat. 3,133,720, May 19, 1964.
\textsuperscript{15}Oelsen, Willy, and Olaf Oelsen. Zur Verteilung von Schwefel und Mangan zwischen Roholschmelzen und Hochofenschlacken (On the Partition of Sulfur and Manganese between Pig Iron Melts and Blast Furnace Slags). Arch. für das Eisenhuttenwesen (Dusseldorf, West Germany). V. 5, No. 5, May 1964, pp. 381–388.
\textsuperscript{17}Fratini, N. The Pozzolanic Properties of Basic Blast Furnace Slag. Silicates Industry, v. 29, Nos. 7 and 8, 1964.