SILICON

By Thomas S. Jones

Domestic survey data and tables were prepared by Lisa D. Miller, statistical assistant.

Silicon (Si) is a light chemical element with metallic and nonmetallic characteristics. In nature, silicon combines with oxygen and other elements to form silicates. Silicon in the form of silicates constitutes more than 25% of the Earth's crust. Silica is a silicate consisting entirely of silicon and oxygen. Silica (SiO_2) as quartz or quartzite is used to produce silicon ferroalloys for the iron and steel industries, and silicon metal for the aluminum and chemical industries. Ferrosilicon and silicon metal are referred to by the approximate percentage of silicon contained in the material and the maximum amount of trace impurities present.

Almost all ferrosilicon products are consumed by the iron and steel industries. In terms of their nominal silicon contents, the two standard grades of ferrosilicon are 50% ferrosilicon and 75% ferrosilicon.

Silicon metal is used by the primary and secondary aluminum industries and the chemical industry, which uses it principally for silicones. Specifications for silicon metal used by the primary aluminum and chemical industries generally are more stringent than those for metal used by the secondary aluminum industry. In addition, the chemical industry requires that the metal be ground into a fine powder rather than the lump form used by the aluminum industry. Silicon metal that is refined into semiconductor-grade metal for use in making computer chips is crucial to modern technology, but the quantity is less than 5% of total silicon metal demand (Roskill's Letter from Japan, 2000). This report contains no information about this highest purity silicon except as it appears in the foreign trade statistics.

For 2000, an overall domestic silicon production of 367,000 metric tons (t) of contained silicon was the least since 1993. Decreases in production and shipments were the most notable in the ferrosilicon category of 56% to 95% silicon content (nominal 75% ferrosilicon), for which the declines were about 30%. On the basis of contained silicon, overall U.S. trade volumes rose by about 26% for imports and decreased by about 33% for exports. The trade category corresponding to nominal 75% ferrosilicon accounted for the majority of imports and increase in import volume. The export decline was associated mostly with silicon metal. The combination of decreased domestic production with increased net imports resulted in record high apparent consumption levels for ferrosilicon, silicon metal, and silicon materials overall; for silicon overall, the increase was 7% to 689,000 t. U.S. net import reliances for silicon materials equaled or exceeded any previous values, rising overall to 47% from 34%. Year-average dealer import prices for standard grades of ferrosilicon and silicon metal decreased for the fourth successive year, by a range of 8% to 12% for ferrosilicon and 6% for metal.

Legislation and Government Programs

The fine of $150,000 given in 1998 to the then-SKW Metals and Alloys Inc. (became CC Metals and Alloys, Inc., in 1999) for ferrosilicon price fixing was upheld in July by the presiding judge for the original criminal trial (Ryan's Notes, 2000c). The amount of the fine subsequently was appealed again by the U.S. Department of Justice (Ryan's Notes, 2000d). The fine being contended had been set by the U.S. District Court for the Western District of New York in Buffalo, NY.

Production

In terms of gross weight and in comparison with those of 1999, overall domestic gross production, net shipments, and stocks of silicon products decreased by about 13%, 16%, and 2%, respectively. The most pronounced year-to-year percentage declines were for the ferrosilicon category of 56% to 95% silicon content (nominal 75% ferrosilicon), for which

Silicon in the 20th Century

Usage of silicon as a ferroalloy in the production of steel and cast iron had been established prior to the turn of the century. Silvery pig iron, a low content silicon ferroalloy generally containing less than 20% silicon, already had been produced using blast furnaces in the 1890s. Electric furnace technology for producing silvery pig iron, ferroalloys with higher nominal silicon contents between 50% and 75%, and silicon metal began to be developed beginning about the start of the 20th century. Production and use of silicon ferroalloys received considerable impetus from World Wars I and II; use of ferrosilicon can be estimated to have paralleled domestic raw steel production, which increased approximately by a factor of 7.5 during the century.

The first significant use developed for silicon as a bulk element was for alloying with aluminum around 1920. After aluminum castings, the second largest use for silicon was production of silicones and related chemicals, which began developing in the 1930s and was accelerated during World War II. A third development, which began shortly after World War II, was usage of relatively small amounts of silicon in high-value, high purity forms in such key electronic devices as computer chips.

In 2000, U.S. production of the various grades of ferrosilicon plus elemental silicon (commonly referred to as metal) was about 400,000 metric tons of silicon content valued at approximately $400 million. Worldwide, in terms of gross weight, production was about 4 million metric tons for ferrosilicon and about 900,000 tons for silicon metal.

production and shipments fell by about 30%. For silicon metal, production and shipments decreased by about 6% and 8%, respectively; stocks decreased only marginally. These comparisons are exclusive of silvery pig iron, statistics for which were not published to avoid disclosing proprietary data. In terms of silicon content and also exclusive of silvery pig iron, overall production of silicon materials was the least since 1993.

Domestic production data for silicon are derived from monthly and annual voluntary surveys and estimates for nonrespondents by the U.S. Geological Survey (USGS). The figures in table 2 represent 100% of the production and shipments from the operations listed in table 3 that are canvassed by means of the Silicon Alloys survey.

American Alloys Inc. stopped production of ferrosilicon and foundry alloys at its Graham, WV, plant after suddenly having declared Chapter 11 bankruptcy on January 26. Low prices and removal of antidumping duties on ferrosilicon from a number of foreign countries appeared to have been among the factors resulting in American Alloys' shutdown (Ryan's Notes, 2000a). This was the second time within 5 months that production was stopped at a domestic smelter where silicon ferroalloys or metal was being produced. After the shutdown, American Alloys sold material in inventory and manufacturing equipment (Platt's Metals Week, 2000; Ryan's Notes, 2000f).

Globe Metallurgical, Inc., with headquarters in Cleveland, OH, already a part owner of Norway's Fesil ASA, made an offer in August for all of the outstanding shares of Fesil, a producer of ferrosilicon and silicon metal (Ryan's Notes, 2000e). The offer was withdrawn early in November after it failed to interest holders of at least 90% of the outstanding shares (Metal Bulletin, 2000).

At Simcala, Inc. unionized hourly workers went on strike as of August 8. No immediate effect of the strike was apparent at the company's silicon metal plant at Mount Meigs, AL, a short distance east of Montgomery, as the striking workers were only a part of the total workforce (Ryan's Notes, 2000i). The strike continued for the rest of the year.

Principal elements in the cost of silicon and ferrosilicon production are the delivered costs of the ore (quartz or quartzite) and costs of energy, reductant coke or low ash coal, iron in the form of steel scrap (if required), and labor. Production of silicon metal and silicon-containing alloys is extremely power intensive and can require up to 14,000 kilowatthours of electric energy per metric ton of silicon contained in the final product (Dosaj, 1997, p. 1105). This high-energy demand can be offset somewhat by recovering heat energy from furnace offgases. Locations of ferrosilicon and silicon metal smelters are usually determined by balancing marketing costs against processing costs.

Silicon is not generally recovered from secondary sources. The only secondary possibility is recovery from metallic scrap, such as aluminum alloys, cast iron, and steel, from which recovery of contained silicon is incidental to that of the primary metal. Some silicon is recycled internally in smelters when fines or offgrade material are remelted.

Consumption

Ferrosilicon was used primarily as a deoxidizing and alloying agent in the production of iron and steel products. Silicon metal, which can be classified into metallurgical and chemical grades, was used by the aluminum industry in the production of cast and wrought products. It also served as the basic raw material in the manufacture of many chemical products and intermediates, such as silicones and silanes. Small quantities of silicon were processed into high-purity silicon for use in the semiconductor industry.

For 2000, total U.S. apparent consumption of silicon-containing ferroalloys and silicon metal was estimated to have increased by about 7% to 689,000 t of contained silicon. Also in terms of contained silicon, apparent consumption increased about 6% to 397,000 t for ferrosilicon and miscellaneous silicon alloys and somewhat more than 8% to 292,000 t for silicon metal. Increases in net imports that outweighed decreases in production resulted in the above three figures for apparent consumption that are thought to be the greatest ever. Still on the basis of silicon content, the share of total demand accounted for by ferrosilicon and miscellaneous silicon alloys remained at 58%. Table 4 presents data on U.S. reported consumption and stocks of silicon materials in 2000.

One supplier of ferroalloys has estimated that its shipments to iron foundries that consisted mostly of magnesium ferrosilicon, inoculants, and standard grades of ferrosilicon have advanced at a combined annual growth rate (CAGR) of 18% between 1992 and 1999 (Ryan's Notes, 2000k). Future growth in shipments to foundries appears likely to be slowed by plans by at least one domestic automobile manufacturer to replace iron by aluminum in engines (Wrigley, 2000).

Particularly in iron foundries, metallurgical-grade silicon carbide can substitute for ferrosilicon. Data on North American production and U.S. imports of silicon carbide were reported in the 2000 annual review of Manufactured Abrasives in the Mineral Industry Surveys series of the USGS and in the Manufactured Abrasives chapter of the 2000 Minerals Yearbook.

Consumption of ferrosilicon and silicon metal was estimated by CRU International Ltd. to have increased in 2000 for all areas of the Western World. In terms of contained silicon, the increase overall was from 1.73 million metric tons (Mt) to 1.83 Mt for ferrosilicon, and from a revised figure of 928,000 t to 1.03 Mt for silicon metal. The 2000 total for silicon metal consumption was the second consecutive alltime high. Areas having the largest year-to-year percentage increases were, for ferrosilicon, Japan and Other Asian countries, and for silicon metal, Japan and Western Europe. In decreasing order, Western Europe, Japan, and the United States accounted for 70% of the 2000 consumption total for ferrosilicon. Also in decreasing order, Western Europe, the United States, and Japan accounted for 84% of that for silicon metal (CRU Bulk Ferroalloys Monitor, 2001b).

For silicon wafers made from polycrystalline silicon, the CAGR between 1999 and 2003 has been forecast as about 10% (Hunter, 2000).

The CAGRs for silicone demand have been assessed as in excess of 10% for Southeast Asia, 4% to 6% for Western Europe and the United States, and 2% to 4% for Japan (Westervelt, 2000). Globally, the CAGR for silicones and silanes between 1995 and 1998 has been put at 6%. Consumption of silicones in the United States has been projected to have a CAGR of between 4% and 6% between 2000 and 2003 (Boswell, 2000). A healthy growth rate in demand also is forecast for silanes that function as coupling agents for fillers used in polymer composites. Sales of silane coupling agents worldwide currently amount to $600 million (Mack, 2000). Expansion of silicones operations overseas has been viewed as presenting a challenge to U.S. producers of silicon metal that serves as feedstock for silicones production. As an example, Dow Corning Corp.'s expansion in Wales has caused Dow Corning's Carrollton, KY, silicones plant to become a "swing" producer (Ryan's Notes, 2000b, g).

Microsilica (silica fume) is a potential byproduct from furnaces making silicon metal or ferrosilicon with a silicon content of at least 75%. It is obtained by capturing furnace offgases and finds use as a binder and filler in cements. The amount of microsilica dust currently being generated from silicon metal furnaces per year worldwide can be estimated to exceed 300,000 t (Kendall, 2000).

Prices

Demand for silicon ferroalloys and metal is determined in the short term less by their prices than by the level of activity in the steel, ferrous foundry, aluminum, and chemical industries. As a result, prices tend to vary widely with changes in demand and supply. The basis for U.S. prices of silicon materials was cents per pound of contained silicon.

Year-average import prices, as given by Platt's Metals Week or as calculated from Platt's weekly listings, were, in cents per pound, 35.4 for 75% ferrosilicon and 54.8 for silicon metal; these prices were about 12% and 6% lower, respectively, than those of 1999. In 2000, yearend prices were lower than those at the beginning of the year by about 3% for 75% ferrosilicon and 5% for silicon metal. For 50% ferrosilicon, beginning in January and continuing through the first week of September, Platt's listed only a price range of 43 to 47 cents per pound, which was the same as at the end of 1999. After the first week of September, Platt's discontinued this price listing. For the 8 months of 2000 this listing was in effect, the average of 45 cents per pound for 50% ferrosilicon was about 8% less than that for all of 1999. The ranges for North American transaction price for 50% ferrosilicon as given by Ryan's Notes were nearly the same as the range given by Platt's. At the point at which Platt's discontinued its listing, Ryan's Notes gave, in cents per pound, 43 to 48, and at yearend, 42 to 48.

The decline in year-average prices for silicon materials continued for the fourth successive year. The year-average price for silicon metal again was the least of any year since 1990. For 75% ferrosilicon and silicon metal, the pattern of price changes was similar for each—a rising trend until the first of April, a plateau, and then an irregular downward trend for the rest of the year. The price range for 75% ferrosilicon, in cents per pound, began the year at 34 to 36.5, slightly below the range of 34 to 37 at the end of 1999, reached and maintained a plateau for 3 weeks at a high point of 37 to 39, and ended the year at 33 to 35.25. For silicon metal, the price range, in cents per pound, began the year at 52 to 53, the same as at the end of 1999, held for 8 weeks at a high point of 58 to 59, and ended the year at 49 to 51.

Causative factors cited by CRU International Ltd. for prices of 75% ferrosilicon that CRU regarded as the lowest ever in real terms included foreign exchange rates, abolition of U.S. antidumping duties, and world oversupply. Prices in the United States that were higher than those elsewhere led naturally to an influx of imports (CRU Bulk Ferroalloys Monitor, 2000). Besides the strong U.S. dollar, a drop in demand from the aluminum industry contributed to the price slide for silicon metal (Ryan's Notes, 2000h).

Foreign Trade

Compared with those for 1999, total volumes of ferrosilicon and silicon metal decreased for exports (-33%) and increased for imports (+26%), on a content basis. The biggest year-to-year changes were for exports of silicon metal and imports of ferrosilicon. On a content basis, overall imports seemingly were the highest ever for ferrosilicon and silicon metal.

U.S. exports of ferrosilicon decreased by about 7% overall in gross weight but increased by about 5% in value. Australia, Canada, India, Japan, the Republic of Korea, Mexico, and the United Kingdom were the recipients of about 90% of total 2000 exports of ferrosilicon (table 5). Exports of silicon metal decreased by 50% in gross weight but increased by about 19% in value. Shipments of high-purity silicon of high unit value that contained more than 99.99% silicon rose 45% to account for about 94% of total value. Shipments in the category of "silicon, other," were only about one-third as great as in 1999. Combined shipments to Canada, Germany, Japan, and Mexico accounted for about 78% of total shipments. Those to Mexico were only about one-fifth those in 1999.

U.S. imports of silicon ferroalloys increased overall by 31% in gross weight and 21% in value compared with those for 1999. Import volumes increased for all significant categories except for ferrosilicon containing 55% to 80% silicon and more than 3% calcium. About 86% of total quantity and 81% of total value were accounted for by imports of nominally 75% ferrosilicon (ferrosilicon category of "55% to 80% silicon, other") (table 6). Reflecting the removal of antidumping and countervailing duties on ferrosilicon in late 1999, this category had the greatest year-to-year percentage increase in volume (39%). Norway continued as the leading overall source of ferrosilicon, although its share of the total fell to 32%.

Overall imports of silicon metal increased by about 14% in volume and 6% in value compared with those for 1999. Imports in the category of "silicon content from 99.00% to 99.99%," displaced those of high-value silicon metal that contained more than 99.99% silicon, in accounting for the largest share of total value, about 45% versus 40%, respectively. Among imports with a silicon content of from 99.00% to 99.99%, import volumes increased by 72% for those from Brazil and by 62% for those from South Africa. For the category of "silicon content less than 99%," imports from Saudi Arabia were only about one-tenth those of 1999. The year-to-year percentage changes in import volumes were -7% for "silicon content more than 99.99%," +36% for "silicon content from 99.00% to 99.99%," and -18% for "silicon, other."

The quantities of silicon metal imported from China were perceived by industry sources to be significantly greater than shown in table 6 because of shipments purportedly via another country, such as the more than 8,000 t of material reported as having come from the Republic of Korea (CRU Bulk Ferroalloys Monitor, 2001a).

For 2000, U.S. net import reliances were estimated to have risen from 38% to 53% for ferrosilicon and from 29% to 38% for silicon metal. The overall import reliance for silicon was estimated to have increased from 34% to 47%. These import reliances for silicon materials are believed to surpass any previous values except that the percentage for silicon metal equals that for 1994.

The general rates of duty that applied to U.S. imports during

2000 were the same as in 1999. These were, on an ad valorem basis, 1.5% for standard 75% ferrosilicon, 1.1% for nominal 75% ferrosilicon that contains more than 3% calcium, free for magnesium ferrosilicon and most other ferrosilicon, and 5.3% or 5.5% for metal exclusive of the high-purity grade (U.S. International Trade Commission, 1999).

Effective with publication of Presidential Proclamation 7388 on December 21, the Generalized System of Preferences (GSP) Program was modified so as to grant duty-free status to certain products from sub-Saharan African countries. Ferrosilicon containing either 80% to 90% silicon or more than 90% silicon were among the products to which this form of GSP treatment now applied (Clinton, 2000). Silicon metal declarable under the import category that specifies a silicon content of less than 99% also had been a candidate for GSP treatment, but its tariff status was not changed (Ryan's Notes, 2000j).

The International Trade Administration (ITA) of the U.S. Department of Commerce published the results of its final or amended final antidumping duty administrative reviews for silicon metal from Argentina and Brazil.

For silicon metal from Argentina, for the period of review (POR) of September 1, 1997, through August 31, 1998, in a review that was specific only to Electrometalurgica Andina S.A.I.C. (Andina), it was found that no sales were made below normal value, so that no antidumping duties were assessed. Margins remained unchanged for other firms not covered in this review, as did the "all other" rate of 17.87% (International Trade Administration, 2000c). The ITA also rescinded its review for the POR of September 1, 1998, through August 31, 1999, for Andina because Andina made no shipments to the United States during this POR (International Trade Administration, 2000b).

For silicon metal from Brazil, for the POR of July 1, 1992, through June 30, 1993, the ITA amended again its final results for Companhia Brasileira Carbureto de Calcio (CBCC) and Eletrosilex Belo Horizonte to margins of 35.43% and 51.84%, respectively. These rates, however, did not change the cash deposit rates in effect for CBCC and Eletrosilex at the time of this amendment, as those rates continued to be based on the margins found in the most recently completed review (International Trade Administration, 2000e). For the POR of July 1, 1997, through June 30, 1998, the ITA determined a margin of 0.05% for CBCC; 18.87% for Eletrosilex; zero for Ligas de Aluminio, S.A., and Rima Industrial S/A; and 91.06% for "all others." The rate for CBCC was effectively zero because of its de minimis character of being less than 0.5% (International Trade Administration, 2000a).

The ITA also concluded expedited 5-year ("sunset") reviews of the antidumping duty orders on silicon metal from Argentina and China. The ITA found that revoking these orders was likely to lead to continuation or recurrence of dumping at weighted-average margins of 17.87% for Argentina and 139.49% for China (International Trade Administration, 2000d, f).

World Review[1]

Data on annual world production of ferrosilicon and silicon metal by country during 1996 to 2000 are given in Fenton [in press (a)]. World production of ferrosilicon was estimated to have been about 4.3 Mt in 2000 compared with a revised total of about 3.9 Mt in 1999. The major producers of ferrosilicon in 2000 were, in decreasing order, China, Russia, Norway, Ukraine, the United States, Brazil, Kazakhstan, France, and South Africa, and accounted for about 85% of total production. World production of silicon metal, excluding that from China, was estimated to have been about 720,000 t in 2000 compared with a revised total of about 700,000 t in 1999. China's production is believed to have been the world's largest, but data are lacking. Available information indicates that China's annual output of silicon metal in recent years was a minimum of 250,000 t (approximate export level) and, considering consumption within China, may have been in excess of 400,000 t. Other major producers of silicon metal in 2000 were, in decreasing order, the United States, Brazil, Norway, France, Russia, and South Africa; they accounted for about 82% of total production as listed in table 1.

Brazil.—In March, Dow Corning Corp. of the United States completed its acquisition of CBCC, which had an annual production capacity of 40,000 t for silicon metal and 20,000 t for ferrosilicon. Dow Corning planned to convert CBCC's facilities within a few years so as to give it the capability of producing 60,000 tons per year (t/yr) of silicon metal (Sissell, 2000). Subsequently, the structure of silicon metal production was changed further when Rima Industrial leased Eletrosilex' facilities having a silicon metal capability of 22,000 t/yr. Rima Industrial also was a producer of silicon as well as ferrosilicon.

Canada.—Bécancour Silicon Inc. described a new technology, termed the SKTEC process, by means of which either 75% ferrosilicon or silicon metal could be produced from the same furnace without any downtime in making a product change. This process has been in use continuously at Bécancour Silicon since late 1997 (Boisvert and Ksinsik, 2000).

China.—In 2000, China's exports of ferrosilicon rose to a total of about 490,000 t, and those of silicon metal totaled about 320,000 t. In 1999, exports of silicon metal exclusive of high-purity grades were 264,000 t, which was about 3% less than those of 1998; almost one-half of 1999 exports were reported to have gone to Japan.

A Government program for improving the efficiency and environmental performance of the country's electrometallurgical industries was underway. Production of ferrosilicon and silicon metal were among the materials to which this program applied, under which older and smaller furnaces were to be phased out.

France.—Invensil, formed in 1999 by combining the silicon metal activities of France's Pechiney Electrométallurgie (PEM) and South Africa's Samancor Ltd., enlarged its silicon capabilities in France and became wholly owned by Pechiney. In the first part of the year, a furnace at PEM's Château-Feuillet plant that was being used to produce calcium-silicon was converted to silicon metal, thus giving Invensil four production sites in France and adding 9,000 t to annual silicon production capacity. Late in the year, Pechiney acquired Samancor's minority interest in Invensil, thereby assuming full control of the Silicon Smelters plant at Pietersburg, South Africa.

India.—Late in the year, the Government recommended preliminary antidumping duties on imports of ferrosilicon from

[1]In a number of instances, discussions of the more significant developments during 2000 for specific countries were based on news items in trade journals, such as American Metal Market, Metal Bulletin, Platt's Metals Week, Ryan's Notes, and TEX Report. These items have not been acknowledged individually because the information they conveyed often was aggregated, possibly with that from other sources.

China and Russia, but not those from Iran. Dumping margins were determined as about 43% for Chinese material and about 57% for Russian material. The Government's investigation was in response to a petition from domestic ferroalloy producers.

Norway.—Approximately 1 year after Fesil ASA had stopped production of silicon metal from three furnaces in the first half of 1999, production was restarted from the two furnaces that still were idle. These were one each at the Holla Metall and Lilleby Metall plants. In November, the affiliation of Switzerland's Gurta AG and the U.K.'s Tensil Ltd. took control of Fesil from Globe Metallurgical of the United States. This change occurred after Globe withdrew an offer by means of which it sought at least 90% of Fesil's shares.

In late 2000, AstroPower Inc. of the United States and Elkem ASA formed a project under which a low-cost process was to be developed for manufacturing solar-grade silicon at a jointly owned plant to be built in Norway. The new plant was to be managed by Elkem and its construction was to begin within 2 years.

South Africa.—As mentioned under France, the Silicon Smelters plant at Pietersburg for production of silicon metal that was a part of Invensil came fully under the control of France's Pechiney.

Silicon Chemicals.—In May, Dow Corning celebrated completion of an expansion of capability for methylchlorosilanes (MCS) at its Barry, Wales, plant. That plant's annual production capacity for these intermediates for production of silicones was approximately doubled to almost 200,000 t (Chemical Week, 2000a). Projects elsewhere for increasing capabilities for production of silicon chemicals included a 30% expansion by Rhodia SA at its plant at Roussillon, France, that would raise by 2002 its capacity for MCS to 200,000 t/yr and for siloxanes to 100,000 t/yr (Chemical Week, 2000c). Also in Europe, the GE Bayer Silicones joint venture between GE Silicones (50.1% ownership) and Bayer AG planned to double by 2002 the MCS production capacity at the Leverkusen plant to 300,000 t/yr (Chemical Week, 2000b). GE Silicones and Japan's Shin-Etsu Chemical Co., Ltd., formed a joint venture to build a plant at a site to be selected in Southeast Asia that would have a production capacity of about 70,000 t/yr for siloxanes (Chemical Week, 2000d).

Current Research and Technology

Investigations relating to the smelting of ferrosilicon and silicon included use of petrographic analysis for selection of coals and cokes to be used as reductants (Buø, Gray, and Patalsky, 2000), determination of material balances for trace elements (Myrhaug and Tveit, 2000; Tveit and Myrhaug, 2000), and modelling of alternating current arcs during typical operating conditions (Sævarsdottir, Bakken, Sevastyanenko, and Gu, 2000).

Laboratory investigations relating to the behavior of silicon in steelmaking systems included study of factors affecting the efficiency of ferrosilicon in reducing chromium oxide from stainless steelmaking slags (Lee, Rhee, Song, and Klevan, 2000) and a determination that silicon additions appreciably reduce the rate of nitrogen dissolution in molten iron (Morita, Hirosumi, and Sano, 2000).

With regard to applications for high-purity silicon, a silane-based process for producing solar-grade silicon from metallurgical-grade silicon was evaluated in the laboratory (Block and Wagner, 2000), and the surface tension of molten silicon was measured under conditions of microgravity (Fujii and others, 2000).

For the A356 aluminum casting alloy (nominally 7% silicon, 0.4% magnesium) commonly used in structural parts of automobiles, the mechanical behavior of silicon particles in the alloy was studied at the high strain rates associated with crashes (Dighe, Gokhale, Horstemeyer, and Mosher, 2000).

Outlook

Demand for ferrosilicon follows trends in the iron and steel industries, for which the CAGRs typically have been in the range of 1% to 2%. Details of the outlook for the steel industry are discussed in the Outlook section of the annual review for 2000 for Iron and Steel (Fenton [in press (b)]. Raw steel production in 2000 increased in the United States by about 4%. Globally, the increase was even greater to give a new record for the world (Reynolds, 2001). Because the U.S. economic downturn in 2000 continued into 2001, however, in the immediate future the outlook was for a slump. The October 2000 midterm forecast for 2000 through 2005 of the International Iron and Steel Institute suggested a slow recovery, as the CAGR projected for the North American Free Trade Agreement countries was only 0.9% (Ian Christmas, Secretary General, International Iron and Steel Institute, October 3, 2000, IISI survey reveals renewed world steel consumption growth, accessed June 1, 2001, at URL http://www.worldsteelorg/trends_indicators/demand.html). For the foundry industry, declines in 2001 were foreseen for nearly all iron and steel castings categories. Longer term CAGRs for the 2000 through 2010 period were given as about 2% for iron castings overall and 0.8% for steel castings (Kirgin, 2001). For the world overall, silicon consumption as ferrosilicon during the first decade of the 21st century was not expected to have a CAGR greater than 1.5% to 2% (Roskill Information Services Ltd., 2000, p. 6).

Demand for silicon metal comes mainly from the aluminum and chemical industries. During the two decades leading up to 2000, Western World demand for silicon has had a CAGR of about 4.7%, and the chemicals sector of this demand has had a CAGR of nearly 7% (Linde, 2000). During the past 5 years, Western World silicon consumption has varied by region, having suffered declines in Asia and uneven growth in the United States (Roskill, 2000, p. 4). On the basis of a forecast for the foundry industry, demand for silicon by the aluminum castings industry can be expected to decline marginally in 2001, but to grow reasonably stronger thereafter until 2010 at an annual rate of 3.8% (Kirgin, 2001). This growth may not translate directly into increased demand for silicon because of an increase foreseen in recycling of automotive aluminum scrap. This adds to uncertainty as to whether Western World demand for silicon can continue to experience a CAGR of greater than 4% (Linde, 2000).

References Cited

Block, H.-D., and Wagner, G., 2000, Technical progress on the Bayer route to low cost solar grade silicon, *in* Øye, H.A., Rong, H.M., Nygaard, Lars, Schüssler, Gunnar, and Tuset, J.K., eds., Silicon for the chemical industry, 5th, Tromsø, Norway, May 29-June 2, 2000, Proceedings: Trondheim, Norwegian University of Science and Technology, p. 271-280.

Boisvert, R., and Ksinsik, D.D., 2000, The SKTEC process, *in* Øye, H.A.,

Rong, H.M., Nygaard, Lars, Schüssler, and Tuset, J.K., eds., Silicon for the chemical industry, 5th, Tromsø, Norway, May 25-June 2, 2000, Proceedings: Trondheim, Norwegian University of Science and Technology, p. 41-50.
Boswell, Clay, 2000, Silicone producers roll out investments: Chemical Market Reporter, v. 258, no. 24, December 11, p. FR24.
Buø, T.V., Gray, R.J., and Patalsky, R.M., 2000, Reactivity and petrography of cokes for ferrosilicon and silicon production: International Journal of Coal Geology, v. 4, nos. 1-4, May, p. 243-256.
Chemical Week, 2000a, Dow Corning opens U.K. plant, plans investment in Asia: Chemical Week, v. 162, no. 20, May 17, p. 20.
———2000b, GE Bayer Silicones to double silanes capacity: Chemical Week, v. 162, no. 15, April 12, p. 24.
———2000c, Rhodia plans rapid silicons [sic] expansion: Chemical Week, v. 162, no. 23, June 14, p. 17.
———2000d, Shin-Etsu, GE Silicones form Asian siloxanes venture: Chemical Week, v. 162, no. 38, October 11, p. 9.
CRU Bulk Ferroalloys Monitor, 2000, Ferrosilicon—Market still dogged by oversupply: CRU Bulk Ferroalloys Monitor, December 19, p. 4.
———2001a, Silicon metal—US anti-dumping duties retained: CRU Bulk Ferroalloys Monitor, January 23, p. 9.
———2001b, Supply/demand balances—Silicon alloys: CRU Bulk Ferroalloys Monitor, April 24, p. 8.
Clinton, W.J., 2000, Proclamation 7388—To modify duty-free treatment under the Generalized System of Preferences for sub-Saharan African countries and for other purposes: Federal Register, v. 65, no. 246, p. 80723-80732.
Dighe, M.D., Gokhale, A.M, Horstemeyer, M.F., and Mosher, D.A., 2000, Effect of strain rate on damage evolution in a cast Al-Si-Mg alloy: Metallurgical and Materials Transactions A, v. 31A, no. 7, July, p. 1725-1731.
Dosaj, Vishu, 1997, Silicon and silicon alloys—Chemical and metallurgical, *in* Kroschwitz, J.I., and Howe-Grant, Mary, eds., Kirk-Othmer encyclopedia of chemical technology (4th ed.): New York, John Wiley & Sons, v. 21, p. 1104-1122.
Fenton, M.D., [in press (a)], Ferroalloys, *in* Metals and minerals 2000: U.S. Geological Survey Minerals Yearbook, v. I.
———[in press (b)], Iron and steel, *in* Metals and minerals 2000: U.S. Geological Survey Minerals Yearbook, v. I.
Fujii, H., Matsumoto, T., Hata, N., Nakano, T., Kohno, M., and Nogi, K., 2000: Surface tension of molten silicon measured by the electromagnetic levitation method under microgravity: Metallurgical and Materials Transactions A, v. 31A, no. 6, June, p. 1585-1589.
Hunter, David, 2000, Silicon wafer makers head for a shakeout: Chemical Week, v. 162, no. 38, October 11, p. 31.
International Trade Administration, 2000a, Final results of antidumping duty administrative review—Silicon metal from Brazil: Federal Register, v. 65, no. 31, February 15, p. 7497-7507.
———2000b, Silicon metal from Argentina; antidumping duty administrative review—Rescission of antidumping duty administrative review: Federal Register, v. 65, no. 4, January 6, p. 758.
———2000c, Silicon metal from Argentina—Final results of antidumping duty administrative review: Federal Register, v. 65, no. 23, February 3, p. 5311-5312.
———2000d, Silicon metal from Argentina; final results of expedited sunset review of antidumping duty order: Federal Register, v. 65, no. 108, June 5, p. 35608-35609.
———2000e, Silicon metal from Brazil; amended final results of antidumping duty administrative review in accordance with court decision: Federal Register, v. 65, no. 100, May 23, p. 33297-33298.
———2000f, Silicon metal from the People's Republic of China; final results of expedited sunset review of antidumping duty order: Federal Register, v. 65, no. 108, June 5, p. 35609-35610.
Kendall, Tom, 2000, Written in sand—The world of speciality silicas: Industrial Minerals, no. 390, March, p. 49-59.
Kirgin, K.H., 2001, Demand for U.S. casting shipments to contract 4% in 2001: Modern Casting, v. 91, no. 1, p. 37-40.
Lee, Sang-Beom, Rhee, Chang-Hee, Song, Hyoseok, and Klevan, Ole-Svein, 2000, Reaction rate of ferro-silicon in the high Cr_2O_3 slag: Electric Furnace Conference 58th, Orlando, November 12-15, 2000, Proceedings, p. 1109-1121.
Linde, J.P. de, 2000, Silicon—A market in transition?, *in* Øye, H.A., Rong, H.M., Nygaard, Lars, Schüssler, Gunnar, and Tuset, J.K., eds., Silicon for the chemical industry, 5th, Trondheim, Norway, May 29-June 2, 2000, Proceedings: Trondheim, Norwegian University of Science and Technology, p. 87-95.
Mack, Helmut, 2000, Tailoring filler surfaces with silanes, *in* Keegan, Nina, ed., Industrial Minerals International Congress 2000, 14th, Denver, March 27-29, 2000, Proceedings: Worcester Park, United Kingdom, Industrial Minerals Information Ltd., p. 103-108.
Metal Bulletin, 2000, Globe withdraws Fesil takeover bid: Metal Bulletin, no. 8524, November 9, p. 7.
Morita, Kazuki, Hirosumi, Taro, and Sano, Nobuo, 2000, Effects of aluminum, silicon, and boron on the dissolution rate of nitrogen into molten iron: Metallurgical and Materials Transactions B, v. 31B, no. 5, October, p. 899-904.
Myrhaug, E.H., and Tveit, Halvard, 2000, Material balances of trace elements in the ferrosilicon and silicon processes: Electric Furnace Conference 58th, Orlando, November 12-15, 2000, Proceedings, p. 591-604.
Platt's Metals Week, 2000, Ferrosilicon producer American needs duties to restart: Platt's Metals Week, v. 71, no. 19, May 8, p. 8-9.
Reynolds, Vicki, 2001, IISI—Steel producers set world output record in 2000: American Metal Market, v. 103, no. 19, January 31, p. 3.
Roskill Information Services Ltd., 2000, The economics of silicon & ferrosilicon (10th ed.): London, Roskill Information Services Ltd., 216 p. plus appendix.
Roskill's Letter from Japan, 2000, Silicon metal—Japanese consumption forecast to rise by 9% in 2000: Roskill's Letter from Japan, no. 286, June, p. 15-17.
Ryan's Notes, 2000a, Chap. 11 for American Alloys; impact and causes debated: Ryan's Notes, v. 6, no. 5, January 31, p. 1.
———2000b, Decision on silicon GSP by end of year: Ryan's Notes, v. 6, no. 42, October 16, p. 2.
———2000c, Ferroalloy notes: Ryan's Notes, v. 6, no. 29, July 17, p. 4.
———2000d, Ferroalloy notes: Ryan's Notes, v. 6, no. 37, September 11, p. 4.
———2000e, Globe launches takeover bid for Fesil: Ryan's Notes, v. 6, no. 34, August 21, p. 3.
———2000f, Nucor tenders hold key to bulk market: Ryan's Notes, v. 6, no. 44, October 30, p. 1.
———2000g, Shopping begins for fourth-quarter silicon: Ryan's Notes, v. 6, no. 35, August 28, p. 2.
———2000h, Silicon cracks under falling demand: Ryan's Notes, v. 6, no. 29, September 25, p. 3.
———2000i, Simcala on strike; no effect anticipated: Ryan's Notes, v. 6, no. 33, August 14, p. 1.
———2000j, US silicon prices continue to creep up: Ryan's Notes, v. 6, no. 52, December 25, p. 3.
———2000k, US SiMn prices test the floor: Ryan's Notes, v. 6, no. 36, September 4, p. 2.
Sissell, Kara, 2000, Dow Corning acquires metals unit from Solvay: Chemical Week, v. 162, no. 12, March 22, p. 16.
Sævarsdottir, G.A., Bakken, J.A., Sevastyanenko, V.G., and Gu, Liping, 2000, Modelling of AC arcs in submerged-arc furnaces for production of silicon and ferrosilicon: Electric Furnace Conference 58th, Orlando, November 12-15, 2000, Proceedings, p. 607-616.
Tveit, Halvard, and Myrhaug, E.H., 2000, Important sub-processes in the silicon process—The behavior of trace elements, *in* Øye, H.A., Rong, H.M., Nygaard, Lars, Schüssler, Gunnar, and Tuset, J.K., eds., Silicon for the chemical industry, 5th, Tromsø, Norway, May 29-June 2, 2000 Proceedings: Trondheim, Norwegian University of Science and Technology, p. 23-30.
U.S. International Trade Commission, 1999, Harmonized tariff schedule of the United States—2000: U.S. International Trade Commission Publication 3249, November 8, variously paginated and unpaginated.
Westervelt, Robert, 2000, Shin-Etsu, GE Silicones form Asian siloxanes venture: Chemical Week, v. 162, no. 38, October 11, p. 9.
Wrigley, Al, 2000, Iron yielding to aluminum in engines at GM: American Metal Market, v. 108, no. 161, August 21, p. 15.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Silicon. Ch. in Metal Prices in the United States Through 1998, 1999.
Silicon. Ch. in Mineral Commodity Summaries, annual.
Silicon. Ch. in Minerals Yearbook, annual.
Silicon. Mineral Industry Surveys, monthly.

Other

Advanced Materials & Processes.
American Metal Market.
Chemical and Engineering News.
Chemical Market Reporter.
Chemical Week.
Company news releases and reports.

European Chemical News.
Ferro-Alloy Directory and Data Book, Metal Bulletin Books Ltd.
Industrial Minerals (London).
Metal Bulletin (London), semiweekly and monthly.
Platt's Metals Week.
Proceedings of ferroalloy conferences (INFACON, etc.)
Roskill Information Services Ltd. (London; last reported on silicon and ferrosilicon in 2000).
Roskill's Letter from Japan.
Ryan's Notes.
Silicon. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.
TEX Report (Tokyo; daily issues and annual ferroalloy manual).
Ultra-high Purity Silicon for Infrared Detectors—A Material Perspective, U.S. Bureau of Mines Information Circular 9237, 1989.