Trends in U.S. Customer Needs for Ferroalloys

by
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ABSTRACT

This paper examines trends in customer needs for ferroalloys in the United States between 1980 and 2000, with emphasis on the 1990's. Changes in ferroalloy production, consumption, and trade are reviewed for each of the major ferroalloys— manganese, silicon, chromium, and nickel—as well as five specialty ferroalloys—molybdenum, vanadium, titanium, niobium, and tungsten. Trends in a number of key statistical variables, such as metal consumption in ferroalloy form, metal consumption in ferroalloy form as a percent of metal consumption, metal consumption in ferroalloy form per ton of steel production, and fraction of metal supply for steel in the ferroalloy form, are compared. This paper also presents ferroalloy-use trends as reflected in the average annual growth rates of consumption, the ferroalloy form percentage of consumption, and use relative to steel production. In addition, sources of U.S. supply, constant dollar price trends, and outlook for U.S. consumption and production are discussed. It was found that each major ferroalloy's share of its respective commodity market has generally remained the same or decreased, while market share has increased in the specialty ferroalloys. In the major ferroalloys, consumption has grown minimally overall from a very strong base in 1980, concurrent with reduced unit consumption. Alternative materials to major ferroalloys, principally alloy scrap and oxide, overall have gained moderately on ferroalloys. A detailed appendix on separate ferroalloys is included.

INTRODUCTION

This report is intended for those studying customer needs for ferroalloys. Ferroalloys are commonly analyzed individually, but usually not in a broader context using common measures by which they may be compared. Performance by these measures is determined in the marketplace through growing demand for higher quality steels, tighter manufacturing standards, and cost advantages of advanced manufacturing technology. These performance measures assist in understanding mineral commodity use and, thereby, facilitate decision making. The U.S. steel industry is the focus of this study because it is the predominant U.S. customer for ferroalloys. Ferroalloy usage in superalloys is important but relatively small. While significant quantities of ferroalloys are used in making cast iron, the general discussion and unit consumption calculations are limited to the U.S. steel industry. More detailed discussion of these and other uses, plus supply and outlook for each of the ferroalloys discussed in this report, is contained in an appendix. Steel production data were obtained from the American Iron and Steel Institute.

The U.S. Geological Survey (USGS) publishes production, consumption, and trade data on all of the ferroalloys discussed, and has less detailed information on a few ferroalloys that are not part of this study, such as ferrozirconium, ferroboron, and ferrophosphorus. The USGS issues reports monthly under the USGS Mineral Industry Surveys series on manganese, silicon, chromium, nickel, molybdenum, vanadium, and tungsten. Quarterly reports are also published on titanium. These reports are posted, along with other information, on the USGS minerals information web page: http://minerals.usgs.gov/minerals.

METALS PRODUCED AND CONSUMED AS FERROALLOYS

Metals produced and consumed as ferroalloys have been categorized by the authors as either major or specialty and are arranged in sequence throughout the paper in descending order of estimated U.S. consumption in 2000, unless otherwise specified. The major ferroalloys division is based on the common grouping of manganese and silicon as bulk ferroalloys, plus the higher consumption tonnage of chromium and nickel relative to any of the specialty ferroalloys. Those referred to as specialty ferroalloys— molybdenum, vanadium, titanium, niobium, and tungsten—are consumed in smaller amounts and are generally of lower total value on an annual basis, although unit values may be higher than those classified as major. Ranges of metal content in common commercial ferroalloys are shown in Table 1.

These ranges represent the typical metal content of commercial ferroalloys, for which the basis metal is normally iron. Table 2 shows the ranges of specified metal content in various grades of
steel, according to definitions provided in the ASM Metals Handbook.[1] These are presented to show the possible content of metal in the more common forms of steel and do not necessarily include all steel grades made. They include both wrought and cast steel but not powder metallurgy steels. Average compositions of the major ferroalloy metals in steel are shown later in this report.

Content in Ferroalloys	
Metal	**Percent**
Manganese	61-90
Silicon	14-79
Chromium	35-82
Nickel	27-46
Molybdenum	55-75
Vanadium	50-86
Titanium	20-70
Niobium	60-70
Tungsten	75-80

Table 1 – Typical range of metal content in ferroalloys.

Metal	Carbon Steel	Alloy Steel	Tool Steel	Stainless Steel
Manganese	0.05 – 1.65	0.05 – 2.1	0.1 – 1.8	0 – 19.0
Silicon	0 – 0.60	0.15 – 2.2	0.2 – 2.5	0 – 4.5
Chromium	0 – 0.25	0 – 3.99	0.15 – 13.5	10.5 – 29.0
Nickel	0 – 0.25	0 – 10.0	0 – 4.25	0 – 37.0
Molybdenum	0 – 0.08	0 – 1.5	0 – 11.0	0 – 7.0
Vanadium	0 – 0.08	0 – 1.0	0 – 5.25	0 – 0.5
Titanium 1/	----	0 – 1.4	----	0 – 2.35
Niobium	----	0 – 0.1	----	0 – 1.25
Tungsten 2/	----	0 – 4.0	0 – 21.0	0 – 1.75

Table 2 – Percent range of ferroalloys metals in steel. Specified metal content derived from ASM Metals Handbook, Second Edition by J.R. Davies, 1998, ASM International, Materials Park, OH. Zero indicates more than 3 alloys with none of the specified metal content. In some cases, the low of the range is a maximum for a particular alloy.
1/ One carbon steel alloy contains about 0.5% Ti.
2/ Tolerated in alloy steel but not required.

Carbon steel is by far the form of steel consumed in the largest quantities, accounting for an estimated 90% of total raw steel production in 2000. Alloy steel, including tool steel, accounted for about 8% and stainless steel 2% of production. According to the American Iron and Steel Institute,[2] steel is considered carbon steel when (a) no minimum content is specified or required for aluminum, chromium, cobalt, molybdenum, nickel, titanium, tungsten, or zirconium; (b) no other element is intentionally added to obtain a desired metallurgical effect, e.g., boron, niobium, or vanadium; (c) the specified minimum for copper does not exceed 0.4%; (d) the maximum content specified for any of the following elements does not exceed the percentages noted: manganese, 1.65; silicon, 0.60; and copper, 0.60. In all carbon steels, small quantities of certain residual elements, such as sodium, are unavoidably retained from raw materials. These elements may be tolerated, but are not normally determined or reported.[3]

For alloy steel, by definition, the maximum range in percent for the content of alloying elements exceeds one or more of the following limits: manganese, 1.65; silicon, 0.60; copper, 0.60. In addition, a definite range or definite minimum quantity of any of the following elements is specified or required within the recognized field of constructional alloy steel: aluminum, boron, chromium up to 3.99, and cobalt, niobium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium, or any other alloying element added to obtain a desired alloying effect.

Stainless steel includes all grades of steel containing 10 percent or more chromium with or without other alloys, or a minimum combined content of 18% chromium and other alloys. Stainless steel has a minimum 50% iron content in its normal composition.

U.S. INDUSTRY NEEDS FOR STEEL CONTAINING FERROALLOY METALS

In 2000, the U.S. economy continued its longest peacetime expansion ever. These favorable economic conditions were reflected in higher steel output for the first half of the year compared with that of 1999, but the second half experienced a downward trend in steel production, which continued into 2001.

Nevertheless, strong construction and motor vehicle manufacturing boosted carbon steel output about 7% for the year. Carbon steel production, in spite of three recessions, has grown an average 1.1% per year over the period 1980 to 2000 (Figure 1). Although alloy metal content of carbon steels is relatively low, the high volume of carbon steel production, an estimated 101 million metric tons in 2000, results in substantial consumption of manganese, silicon, chromium, nickel, molybdenum, and vanadium.

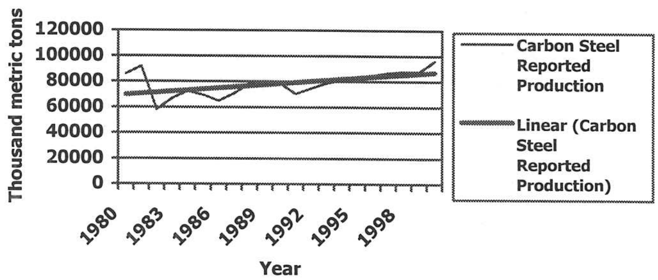

Figure 1 – Carbon steel production in the United States, 1980 – 2000. Carbon steel production trended upward at 1.1% per year. Data source: American Iron and Steel Institute (AISI)

While motor vehicle manufacturing has increased with the growing economy, growth in steel use has been restrained because of competition from other metals and plastics to reduce weight, as well as motor vehicle part unit reduction of steel mass for the same reason. With rising gasoline prices and the likelihood of government fuel economy standards being applied to trucks, significant changes in vehicle weight eventually will be required.[4] This can be partially accomplished, to the detriment of steelmakers, by conversion of cylinder heads and whole engine blocks from iron to aluminum, and through increasing use of smaller engines and electronic-controlled transmissions. Moreover, new motor vehicle models may reflect a growing trend away from steel in certain structural, drive train, and suspension system components, including internal seat frames, fuel tanks, and instrument panel substrates. It is possible that aluminum will continue to replace steel in wheels, undercarriage cross members, and supports.

Motor vehicle industry analysts are inclined to believe that the greater amount of steel in the main structure of larger models will compensate for reduced usage of steel in certain hang-on parts and unexposed structural and drive train components. Engineers are increasingly requiring better formability, strength, weight reduction, and corrosion protection in new steel parts. Some parts are being made from light-weight tailored blanks (for stamping) or tubing. High-strength grades of steel are now used for inner door panels, floor pans, engine cradles, side-door impact beams, bumper beams, and frames. Use of high strength tube steel is becoming increasingly important in weight reduction and maintaining steel's use in motor vehicles. Therefore steel use per vehicle, on average, could decline even though it may not be replaced in certain parts. On the other hand, the alloy content of this reduced steel requirement may increase to obtain the desired properties.

Auto company engineers are increasingly designing vehicles and parts with alternative materials, such as aluminum, magnesium, and plastics, as these materials are proven durable in new applications. As such, companies are increasingly inclined to use them.[5] The trend appears to be one of increasing materials substitution. Steelmakers, on the other hand, are promoting the holistic vehicle design concept—designing a vehicle as an integrated system rather than a collection of separate parts. In this way, they believe that conversion programs using relatively expensive alternative materials can be avoided.[6,7]

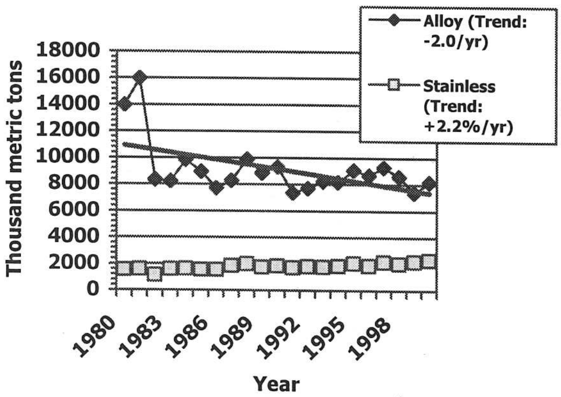

Figure 2 – U.S. alloy and stainless steel production, 1980 – 2000. Data source: AISI

The growth rates of alloy and stainless steel production in the United States have moved in opposite directions over the period 1980 – 2000 (Figure 2). While the growth of stainless steel at 2.2% per year was twice that of carbon steel, the average growth of alloy steel was –2.0%. The marked drop in alloy steel production in the recession of 1981-82 is partly responsible for the negative 2% growth from 1980 to 2000, and trade data show clearly that net imports as a percent of U.S. apparent consumption of alloy steel have filled the gap in supply. Imports have suppressed growth and to an extent displaced U.S. production, but lack of alloy steel production capacity contributed to the decline. Net alloy and stainless steel imports as a percent of apparent consumption of each have risen dramatically, trending upward 23% per year on average for alloy steel and 6.6% per year for stainless steel (Figure 3). A recent reversal of this trend is attributed to a recovery in Asian steel markets, which resulted in lower imports to the United States.

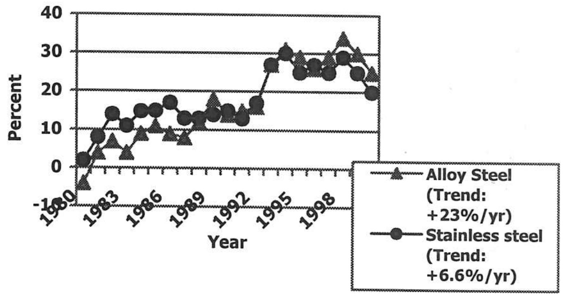

Figure 3 – U.S. net imports of alloy and stainless steel, 1980 – 2000 (as percent of apparent consumption of each). Data source: AISI

Nevertheless, U.S. stainless steel production has shown a slow but steady positive growth. Figures 4 and 5 show the sources of U.S. alloy and stainless steel imports, averaged over the period 1989 – 1998. The European Union, Canada, and Japan are the dominant sources, with Canada the largest source for

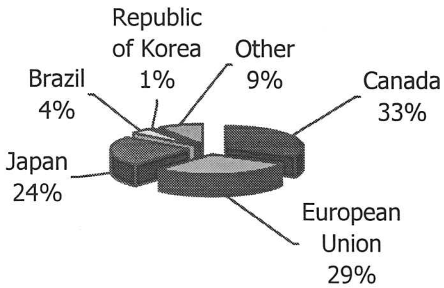

Figure 4 – U.S. alloy steel imports, 1989 – 1998 (percent of total imports). Imports over 1989-1998 period: 21,068,000 metric tons. Data source: AISI

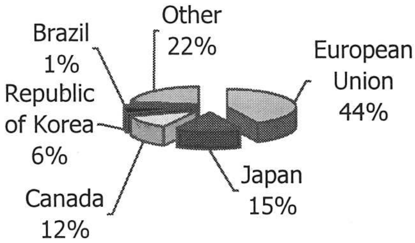

Figure 5 – U.S. stainless steel imports, 1989 – 1998 (percent of total imports). Imports over 1989-1998 period: 6.7 million metric tons. Data source: AISI

alloy steel imports, and the European Union a close
second. The advanced production base of the European Union enhanced by mergers has contributed to the growth in U.S. stainless steel imports. This trade pattern is not expected to change over the next 5 years. New requirements for specialty steels in specialized markets have been the driving force for the development of many new alloys, including stainless steels. Stainless steel producers continue their constant search for new steels through research into the effect of changes in chemical composition. Two areas of focus are the development of the "super-ferritics" with a high chromium content, used in concentrated acid containment applications, and the development of "utility" low-chromium ferritic stainless steel. Important innovations in steelmaking technology have been made as well. Rolling wider sheet coils is as much as 25% less expensive than production of discrete plate, while it increases its availability for use in new markets at lower cost. Untreated stainless steel has an aesthetic metallic appearance. However, by an electrochemical process it can now be processed in a number of colors, including gold, bronze, green, blue, and black.[8]

Stainless steel has found increasing applications in the motor vehicle industry. Manufacturers are able to offer longer warranty guarantees by the use of high corrosion-, moisture-, and heat-resistant stainless steel in body parts, exhaust systems, and engine parts, such as high performance bearings and pistons. Stainless steel has a desirable strength-to-weight ratio needed for new car body designs, and it is ductile and weldable, allowing special shapes to be constructed easily. Wastewater treatment plants increasingly use stainless steel because of its unique properties. Bacteria that would adhere to surfaces and impede flow do not adhere well to polished stainless steel surfaces.

Because stainless steel is corrosion and abrasion resistant without the need for coatings that break down in time, it is increasingly useful in many industries and applications: chemical production plants, petroleum refining, food processing, offshore oil and gas exploration platforms, sea water desalination, textile and paper manufacturing, jet engine manufacture, yacht construction, and radioactive waste management. In the transportation industry, stainless steel is used in rail wagons for coal and cement, public vehicles, and chutes and hoppers used to transport raw sugar, vegetables, and grain. In the construction industry, stainless steel rebar is finding a growing market, particularly for bridges in northern climates subjected to the continual corrosive onslaughts of salt de-icers, or for those in coastal areas subjected to exposure to sea water. Stainless steel is being used increasingly in building parts and street electrical cabinets.

Consumption of alloy and stainless steel is increasing as new uses are discovered and as demand increases in countries with growing population, especially in developing countries. At the end of its useful life, stainless steel is easily recyclable as evidenced by the increasing recycling rates of its constituent metals.

FERROALLOY PRODUCTION IN THE UNITED STATES

Compared with the major ferroalloy-producing countries, U.S. ferroalloy production is moderate in silicon and manganese, but relatively low in other ferroalloy metals. Consequently, U.S. ferroalloy production meets only a small percentage of domestic demand. One important exception is ferrosilicon. For all forms of silicon, the United States has been meeting about 70% of its needs. In countries with competitive mineral resources, the trend is toward production of value added products, particularly in the case of chromium. Because of the unlikely prospect of new or expanded U.S. production and because of the uncompetitive U.S. mineral resources for most of the ferroalloy metals, the overall domestic ferroalloy production trend is one of decline. Nickel and chromium are prime examples. By 1999, U.S. production of ferronickel and common grades of ferrochromium in the United States had ceased. In both cases, when production stopped, ore resources were low-grade, producers were relying on imported ore for feedstock, and operating costs were high. In contrast, ferrosilicon and ferromanganese production have fluctuated, but have been relatively healthy. (See Figure 6.) Ferromanganese production cannot be disclosed so it is not displayed in Figure 6, but it has been recovering from a sharp drop in the early 1980's.

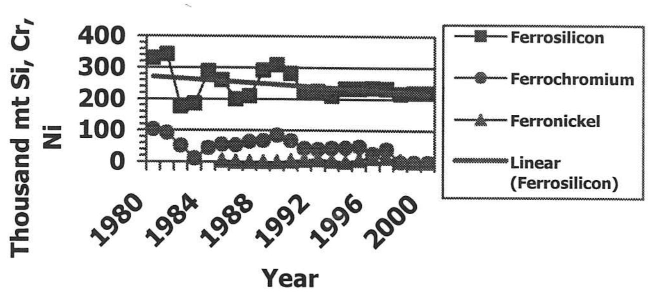

Figure 6 – U.S. ferrosilicon, ferrochromium and ferronickel production, 1980-2000. Ferrosilicon production declined 1.1%/yr, on average.

All of the specialty ferroalloys, except ferrotungsten, are produced in the United States, but production is limited. Between 1980 and 2000, estimated ferrovanadium production trended downward, about 2.7% per year, and ferroniobium trended downward about 4.8% per year (Figure 7). In each case, production of contained metal was less than 5,000 tons per year. U.S. ferromolybdenum production is rising at about 8% per year but remains relatively low, less than 300 tons per year. Figures are not available for U.S. ferrotungsten and ferrotitanium production. U.S. production of the major and specialty ferroalloys is likely to follow the trend in production of steel of all types over the next several years.

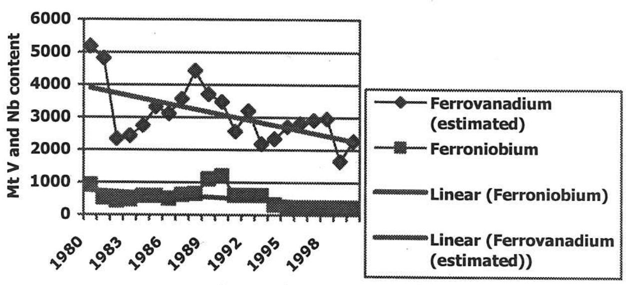

Figure 7 – U.S. ferrovanadium and ferroniobium production, 1980-2000. FeV trended downward 2.7%/yr, FeNb downward 4.8%/yr.

U.S. FERROALLOY CONSUMPTION AND PRICE

Of the major ferroalloys, manganese consumption dominates on a contained weight basis, comprising 49% of the total combined weight of manganese, silicon, chromium, and nickel used in alloying. Chromium is second at 28%, followed by silicon (21%) and nickel (2%) (Figure 8). However, by value of consumption, silicon is highest at 40%, followed by manganese (29%), nickel (16%) and chromium (15%). For the specialty ferroalloys, by weight, U.S. consumption of molybdenum (27%), vanadium (25%), titanium (24%), and niobium (21%) are all nearly equal, with tungsten a distant fifth at 3% (Figure 9). Value ranking shows a somewhat similar pattern, except that niobium is highest at 34%, followed by vanadium (28%), molybdenum (23%), titanium (13%) and tungsten (2%). Table 3 shows estimated U.S. ferroalloy production, consumption, and imports for 2000, with principal import sources.

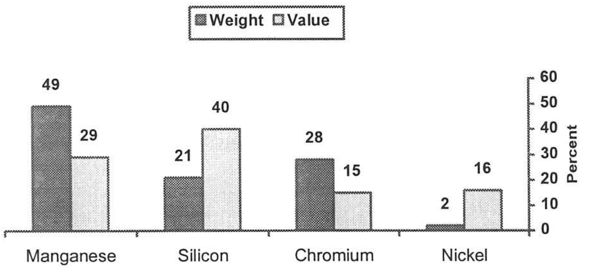

Figure 8 – Major U.S. ferroalloy consumption in 2000 (percent of combined weight of major ferroalloys and percent of their combined value, on a metal content basis). Manganese includes silicomanganese and manganese metal.

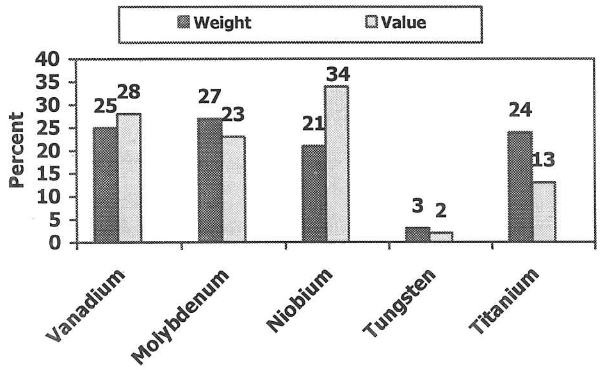

Figure 9 – Specialty U.S. ferroalloy consumption in the United States in 2000 (percent of combined weight of specialty ferroalloys and percent of their combined value, on a metal content basis).

Relative to a particular commodity's overall market, the ferroalloy fraction of each commodity's market has remained relatively stable for manganese and nickel, but has declined slightly between 1980 and 2000 for chromium and silicon. For some metals, the ferroalloy form is the major use for that commodity. For example, manganese as ferromanganese comprised 87% of the total manganese market in 2000. The percent ferroalloy usage of the total market for chromium, silicon and nickel are smaller than that for manganese owing to other uses for these metals in applications in which use of the ferroalloy is not appropriate for technical reasons (Figure 10).

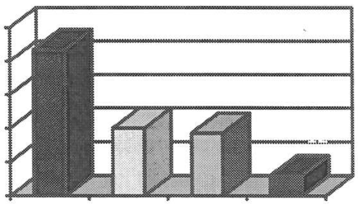

Figure 10 – Ferroalloy percent of total mineral commodity U.S. consumption in 2000 (major ferroalloys).

The specialty ferroalloys comprised an increasing share of their respective markets over the same period, with tungsten rising the most, at 5.5% per year, and molybdenum second at 2.7% annually, on average.

In 2000, ferrovanadium and ferroniobium were estimated to be the dominant forms used in their markets (Figure 11).

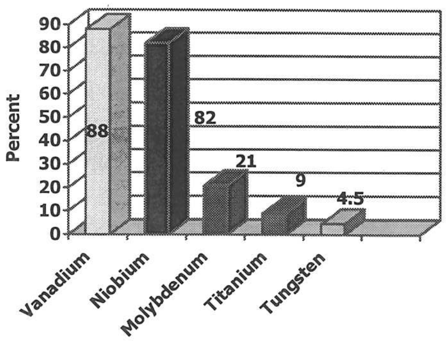

Figure 11 – Ferroalloy percent of total U.S. mineral commodity consumption in 2000 (specialty ferroalloys).

Consumption of the bulk ferroalloys manganese and silicon, on the basis of reported data, has shown flat or negative growth from 1980 to 2000, partly owing to the unusually high level of consumption in 1980 and 1981, particularly for manganese. Another reason for these growth patterns is the greater efficiency of use and use of alternative materials, even as general economic conditions were strong and showing positive growth (Figure 12). Another factor is rising imports of durable goods and automobiles in which steel of various grades and types is used. Apparent consumption calculations indicate that manganese ferroalloy consumption actually showed a recovery beginning in the mid-1980's. Chromium and nickel consumption as ferroalloys, however, trended upward on average only slightly, on an

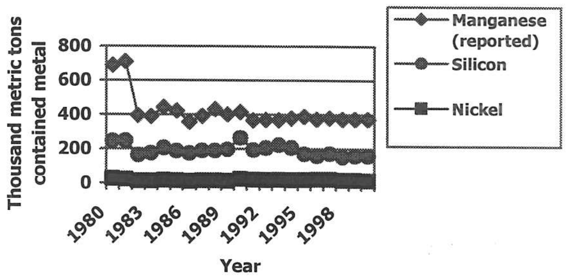

Figure 12 – U.S. ferroalloy consumption, 1980-2000 (major ferroalloys, except chromium). Manganese includes silicomanganese and manganese metal.

Metal	U.S. Production	U.S. Consumption	U.S. Imports	Principal Import Sources (Percent from each)
Manganese	W	375,000	275,000	South Africa, 36; Australia, 13; Mexico, 10.
Silicon	220,000	1/ 350,000	150,000	Norway, 32; Kazakhstan, 23; South Africa, 9; Venezuela, 8.
Chromium	0	210,000	200,000	South Africa, 41; Kazakhstan, 27; Turkey, 15.
Nickel	0	17,000	17,500	Dominican Rep., 46; New Caledonia, 30; Colombia, 11.
Molybdenum	275	4,040	5,660	China, 53; United Kingdom, 45.
Vanadium	2,000	4,000	2,000	Canada, 64; China, 12; South Africa, 12; Austria, 9.
Titanium	NA	3,600	4,000	United Kingdom, 80; Russia, 15.
Niobium	230	3,200	4,000	Brazil, 86; Canada, 13.
Tungsten	NA	500	550	China, 84; United Kingdom, 10; Russia, 6.

Table 3 – Estimated U.S. ferroalloy production, consumption, and imports in 2000 (metric tons, contained metal).
W – Withheld. NA – Not available.
1/ Apparent consumption.

annual basis (Figure 13). The specialty ferroalloys show a different picture. Trend line growth in all was generally positive, if only slightly, even though most dropped at the beginning of the period and some declined toward the end. From 1980, tungsten showed the highest growth (Figures 14 and 15). The

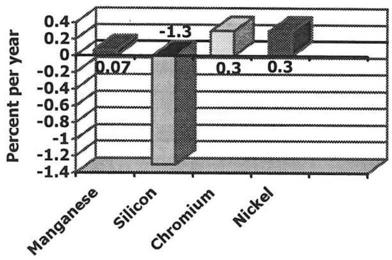

Figure 13 – Average U.S. consumption growth rates for major ferroalloys (trend line growth, 1980-2000).

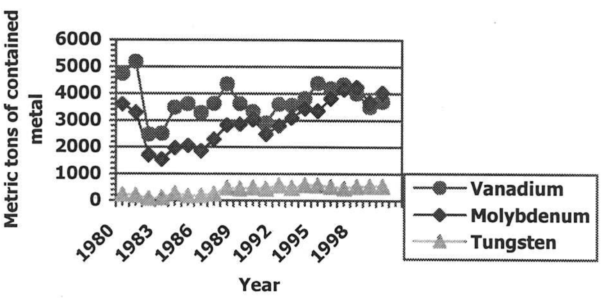

Figure 14 – U.S. ferroalloy consumption, 1980-2000 (specialty ferroalloys, except Ti and Nb). consumption patterns of the specialty ferroalloys were also more variable, and similar to each other, apparently tied more closely to changes in economic conditions. While specialty ferroalloys consumption and alloy steel production both showed a precipitous drop in 1981-82 (Figures 2 and 14), specialty ferroalloys consumption, along with stainless steel production, showed an upward trend thereafter, as opposed to a downward trend for alloy steel production. This may indicate a greater inclination by steelmakers to use ferroalloy rather than scrap or other alternative forms for specialty ferroalloys and a trend toward use of alloys with higher specialty ferroalloy metal content. A common thread that is partially responsible for generating such positive growth is the corrosion resistance and strength imparted by these metals.

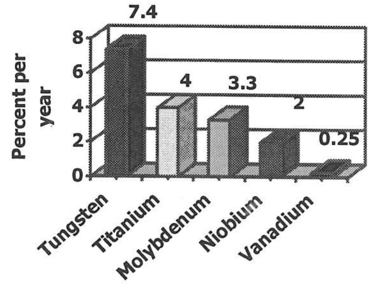

Figure 15 – Average consumption growth rates for specialty ferroalloys (trend line growth, 1980-2000).

The raw steel shipments to production ratio is an indication of how efficiently steel is being made into products for shipment, assuming consistently minimal inventories, and a high ratio represents a reduction in home scrap generation. The widespread use of continuous casting, an efficient technique in which the cast shape is continuously drawn through the bottom of the mold as it solidifies, has helped raise this ratio to close to 1 for carbon steel. Since 1986, continuous casting has risen from 55% to 96% of total raw steel production. Commensurate increases in this ratio have been shown in stainless and alloy steel. The drop in the alloy steel ratio after 1987 reflects the removal of high strength low alloy steel from alloy steel shipments by AISI and therefore results from a change in the organization of statistics rather than a change in industry material use. As shown in Figure 16, this ratio continued to rise after 1987. With increasing quantities of continuous cast steel, there is less ferroalloy use, in whatever form, per ton of steel shipped because of the higher product yield.

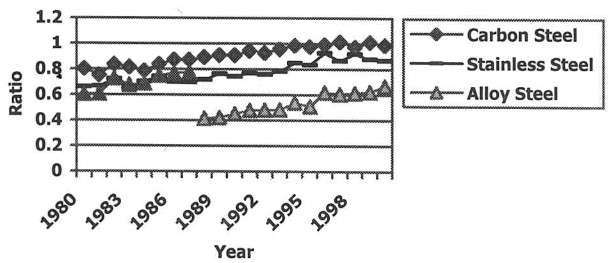

Figure 16 – U.S. steel shipments to production ratio, 1980-2000 (offset in alloy steel series is a result of revision in product categories).

Unit consumption is defined in this study as consumption of ferroalloy metal per ton of raw steel production and is a measure of the fundamental or basic use of ferroalloys. A decline in unit consumption of ferroalloys could offset or exceed the effect of a rise in steel production on ferroalloy usage, resulting in a net decline in ferroalloy consumption. However, unit consumption statistics must be read with caution. To be meaningful, in calculating unit consumption, the ferroalloys consumed should be divided by production of steel grades in steel classifications in which most grades contain the commodity. If not, a change in unit consumption may be due to factors unrelated to consumption changes in the commodity-bearing alloys. For this reason, only the major ferroalloys and molybdenum will be discussed, as they are found in groups of steel grades, most grades of which contain these ferroalloying metals.

The use of ferroalloys per ton of raw steel melted is not significantly affected directly by use of continuous casting. However, microalloying is becoming increasingly important as modern steelmaking practice moves toward eliminating reheating of continuously cast steel by rolling the steel directly after casting. Microalloying refers to the improvement of formability and toughness of low-carbon steel by the addition of niobium, titanium, vanadium and other metals to favorably affect its microstructure.[9] On the other hand, the content of certain oxidizible metals in steel, such as chromium, manganese, silicon, and titanium, may be reduced in the steelmaking process.[3] The net result of these and other steelmaking practices seems to have been a greater efficiency of use of raw materials with consequent reduction in unit consumption for the major ferroalloys.

All of the major ferroalloys showed negative growth for unit consumption of the ferroalloy form (material), which is measured as kilograms of consumption per ton of steel produced (Figure 17).

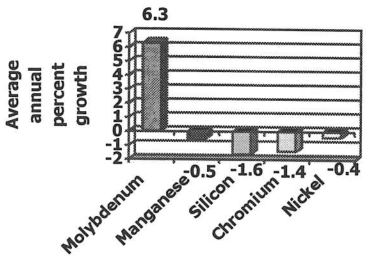

Figure 17 – Trend line growth rate of U.S. unit commodity consumption (major ferroalloys and ferromolybdenum, 1980-2000).

Unit consumption of contained manganese and silicon (as supplied through ferroalloys) used to make steel of all types steadily declined between 1980 and 2000. The average annual rate of decline for manganese was 0.5%/yr, demonstrating the greater efficiency of manganese usage in steelmaking, a process technology advance. The same is true of silicon (-1.6%/yr). Manganese and silicon are unique as compared with most other ferroalloys in that in addition to having a product function as a component of the steel produced, they also have a process function, e.g., sulfur removal and/or deoxidation. Therefore, their unit consumption is influenced by some additional factors. This decline in unit consumption is an important demonstration of how technology works to reduce costs and conserve resources.

Ferrochromium and ferronickel unit consumption calculations were based on consumption relative to stainless steel production and showed similar declines (Figure 18).

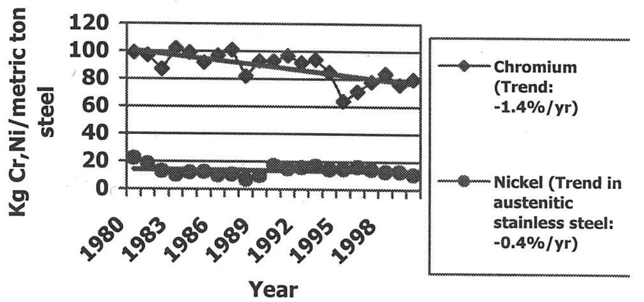

Figure 18 – Unit consumption of FeCr and FeNi in U.S. stainless steel, 1980-2000.

For 1980 and 2000, consumption of all forms of manganese, silicon, chromium, and nickel units per ton of steel produced was compared with unit consumption of their respective content of ferroalloys per ton of steel production. As with unit consumption of ferroalloys, each of the foregoing commodities showed a decline, indicating greater efficiency of use both in the manufacture of steel products and in the alloy products themselves, whereby equivalent properties may be obtained with less alloy metal. The difference between these two measures—unit consumption of ferroalloys and unit consumption of total alloying metal units—represents the scrap, oxide, or other materials fraction used to supply metal units in steelmaking. As shown in Table 4, this fraction for manganese, silicon, chromium, and nickel has grown since 1980 at the expense of ferroalloys. The percent decline in the ferroalloy fraction for the major ferroalloy metals in 2000 as compared with that of 1980 is shown in table 5. The exception to this trend seems to be molybdenum, which showed an increase in unit consumption (Figure 19). This is probably due to product technology advances, in which the use of molybdenum is tied directly to corrosion warranties and weight reduction in motor vehicle applications. Greater use of corrosion resistant duplex steels, with

	Average Consumption		Material Composition	
Metal	Total Metal as Ferroalloy in Steel	Metal in Steel	Ferroalloy Fraction of Metal Supply	Scrap and/or Oxide Fraction of Metal Supply*
		1980		
Manganese 1/	0.7	1.13	61.9	38.1
Silicon 1/	0.135	0.288	46.9	53.1
Chromium 2/	9.9	20.3	48.8	51.2
Nickel 3/	2.23	7.75	28.8	71.2
Molybdenum 4/	0.0121	0.0942	12.8	87.2
		2000		
Manganese 1/	0.6	1.00	60.0	40.0
Silicon 1/	0.095	0.255	37.3	62.7
Chromium 2/	8.0	17.6	45.5	54.5
Nickel 3/	1.08	7.94	13.6	86.4
Molybdenum 4/	0.0281	0.0866	32.4	67.6

Table 4 – Average ferroalloying metal consumption in steel and material composition of metal supply for steelmaking, 1980 and 2000 (percent).
* May also include metal, sulfide, carbide, or concentrate.
1/ Manganese and silicon in total steel.
2/ Chromium in stainless steel.
3/ Nickel in austenitic stainless steel.
4/ Molybdenum in alloy and stainless steel.

Metal	**1980-2000 Percent change**
Manganese	-3%
Silicon	-15%
Chromium	-8%
Nickel	-53%
Molybdenum	+153%

Table 5 – Percent change in ferroalloy fraction of alloy metal consumption for U.S. steelmaking, 1980-2000.

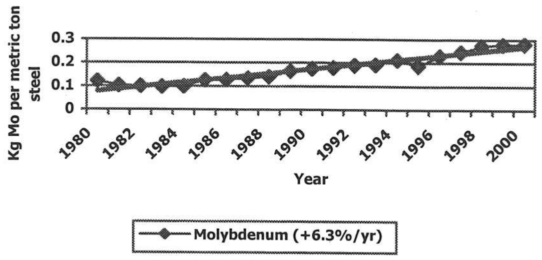

Figure 19 – Unit consumption of Mo in ferromolybdenum in U.S. alloy and stainless steel, 1980-2000. Alloy steel includes tool steel.

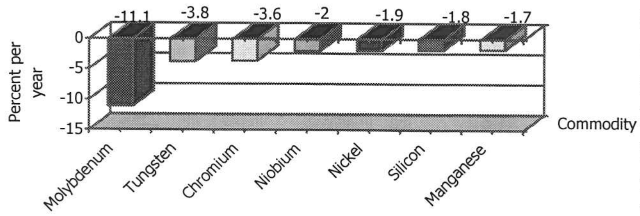

Figure 20 – Constant dollar price trends for ferroalloys.

a relatively high molybdenum content, are expected to cause this trend to continue.

Commonly the most important factor in determining choices of raw materials to supply metal units for steelmaking purposes is the properties that can be obtained from a unit of a particular ferroalloy per dollar spent, provided process metallurgical considerations, such as deoxidation and carbon and nitrogen control, are not overriding. This determines which form of an alloy metal will be used and whether one alloy metal will be substituted for another. For example, a substantial increase in the price of vanadium compared with that of niobium would be expected to increase the use of niobium in steel and reduce the use of vanadium. If the cost of nickel rises high enough relative to manganese and chromium, the usage of manganese and chromium, relative to nickel, might increase if the same properties could be obtained, even though complete substitution may not be possible at this time. Price changes can vary considerably by commodity, of course, but ferroalloy prices seem to have at least one thing in common—a downward trend since 1980 in terms of constant 1992 dollars, the declines ranging from 12%/yr to 3%/yr (Figure 20 and Table 6). Prices for vanadium and titanium were not available over a 20-year period for the series used. However, virtually all metals demonstrate this trend, which is believed to be attributable to technological improvements. Prices were expressed in 1992 constant dollars to show the effects of inflation as measured by the U.S. Bureau of Labor Statistics' Consumer Price Index for All Urban Consumers, a widely used measure of overall inflation in the United States.[10] Over a 20-year span, because ferroalloy prices have not kept pace with inflation, revenues received by ferroalloy producers have less purchasing power. However, constant dollar prices that producers pay for many raw materials have decreased as well, enabling most producers to sustain operations. The world ferroalloy industry over the previous 20 years has shown itself to be resilient in the face of uncertain but generally strong markets, particularly in the United States.

Ferroalloy producers in the United States and other countries will likely continue to be under pressure to become ever more efficient and lower their production costs, such as labor, energy, and materials, in response to this trend of lower relative prices.

		Trend	Ferroalloy	Trend Line Ferroalloy Percent of	Unit Consumption of Ferroalloy	Unit	Constant Dollar

Metal	U.S. Production Trend Line Growth Rate, 1980 - 2000	Line Usage Growth Rate, Percent per Year 1980 – 2000	Percent of Total Commodity Consumption, 2000	Consumption Growth Rate, Percent per Year 1980 - 2000	(Kilograms per Metric Ton of Steel Production) 2000)	Consumption Growth Rate, Percent per Year 1980 - 2000	Price Trend Growth Rate, Percent per Year 1980 - 2000
Manganese	W (+)	+0.07	87	+0.2	1/ 6.0	-0.5	-1.7
Silicon	-1.1	-1.3	35	-3.4	1/ 0.95	-1.6	-1.8
Chromium	2/ -8.3	+0.3	40	-1.3	2/ 80.0	-1.4	-3.6
Nickel	3/ +7.1	+0.3	12	-0.4	3/ 10.8	-0.4	-1.9
Molybdenum	4/ +8.6	+3.3	21	+2.7	4/ 0.3	+6.3	-11.1
Vanadium	5/ -2.7	+0.25	88	+0.4	6/ 0.03	-0.6	7/ +0.6
Titanium 8/	NA	+4	9	+1.7	6/ 0.3	-7.8	8/ +4.8
Niobium	-4.8	+2	82	-0.3	6/ 0.03	+1.6	-2
Tungsten	---	+7	5	+5.5	6/ 0.06	+10.8	9/ -3.8

Table 6 – Salient Statistics for Ferroalloy Trends, 1980-2000.
W – Withheld. NA – Not available. --- Zero.
1/ Unit consumption based on total steel production.
2/ Domestic ferrochromium production currently zero. Unit consumption based on stainless steel production.
3/ Domestic ferronickel production currently zero; positive growth rate is anomalous. Unit consumption based on austenitic stainless steel production.
4/ Domestic ferromolybdenum production, 1984-2000; not available in prior years. Unit consumption based on alloy plus tool steel production.
5/ Estimated.
6/ Unit consumption based on total steel production; including many alloys containing none of the specified metal.
7/ 1994-2000; not available in prior years.
8/ 1985-2000 for all columns except those that apply only to 2000 and constant dollar price trend (1992-2000); not available in prior years.
9/ 1985-2000.

CONCLUSIONS

Over the period 1980 – 2000, in the major ferroalloys, the silicon share of its overall commodity market has decreased, while the shares have not changed appreciably for manganese, chromium, and nickel. Decreased share reflects greater use of alternative materials, such as scrap, in steelmaking, and/or increased commodity consumption in end use areas other than steel. In the specialty ferroalloys, the ferroalloys share of their respective commodity markets has increased from a relatively low base. Increased share suggests increased unit consumption and/or a decline in commodity consumption in end use areas other than steel. In the major ferroalloys, consumption has grown minimally overall from a very strong base in 1980, concurrent with reduced unit consumption. Also in the major ferroalloys and probably some specialty ferroalloys, alternative materials to ferroalloys use, principally alloy scrap and oxide, overall have gained moderately on ferroalloys use over the past 20 years. A combination of factors, including technology and price, is responsible for the decline in unit consumption and market share held by most major ferroalloys. These and other measures of U.S. consumption of ferroalloys are summarized in Tables 5 and 6.

U.S. customer needs for ferroalloys in alloy and stainless steel for a multitude of applications have been and will continue to be strong, even while the steel industry continues to improve processing technology to reduce raw materials needs, and metallurgists develop steel grades with lower alloying metal content and equal or better performance to lower costs. For many stainless steel applications there are no acceptable substitutes, and its key constituents, chromium and nickel, are essential. As technology and industry practices result in greater efficiency of use of ferroalloys, the strong end use demand for metals in construction, the chemical industry, transportation, and household appliances is expected to more than offset any basic reduction in unit consumption in the future. Aerospace and environmental control applications have been an important component of the consumption base as well. Competition from other materials such as plastics and nonferrous metals in the transportation sector will be strong, but the use of light-weight, high-strength steel is expected to make steel competitive for many years.

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Manganese, silicon, chromium, nickel, molybdenum, vanadium, titanium, niobium and tantalum, tungsten, ferroalloys (general), metals recycling, iron and steel scrap, and iron and steel are published as annual reports in the USGS Mineral Industry Surveys series and ultimately are published in the USGS Minerals Yearbook. Annual reports include world production data and detailed discussions of industry events that took place during the year. The USGS Mineral Commodity Summaries, published in January each year, contains all commercial metal and mineral commodities, and is the earliest report available with estimates for the previous year's data.

APPENDIX
SUPPLY, CONSUMPTION, AND OUTLOOK FOR FERROALLOYS

FERROMANGANESE
by
Thomas S. Jones

Supply

During 1980-2000, only electric furnaces were used to smelt ore into manganese ferroalloys. In 1980, ferromanganese and silicomanganese were produced at six plants in the United States, and silicomanganese only was produced at two other plants; six companies in all. As of 2000, ferromanganese and silicomanganese were produced at only one location, Marietta, OH. The plant at this site has been the largest producing plant during 1980-2000 and the one producing manganese ferroalloys since 1990. Ownership of this plant has changed twice, from Union Carbide Corp. to Elkem Metals Co. to Eramet. Continuance of production at this plant was promoted by the Government's program of domestically upgrading ore in the National Defense Stockpile into ferromanganese, an 11-year program that was concluded by December 31, 1994. Only the production of manganese metal by Kerr-McGee Chemical LLC at Hamilton, MS, has remained under domestic ownership.

Supply from foreign countries of manganese ferroalloys, especially that of silicomanganese, proliferated after the Soviet Union dissolved in December 1991. Trade disputes arose in 1993-94 that led to imposition of antidumping duties on silicomanganese from Brazil, China, and Ukraine. France and South Africa regularly have been the leading sources of imported ferromanganese, together accounting for about two-thirds of the total. South Africa's share of these imports has been about 1.4 times as great as that of France. Accompanying a growth from 28% to 47% of the electric furnace's share of domestic steel production, the ratio of ferromanganese to silicomanganese in imports decreased from about 8:1 to about 1:1 during 1980-2000.

Scrap has not had a direct effect on supply of manganese for steelmaking because of the oxidizing nature of steelmaking. Manganese recycling in steel scrap is incidental to that of iron, and only a small amount of scrap is recovered specifically for its manganese content. The amount of manganese being returned to steel plants in scrap, however, is significant compared with that added from ferroalloys. The scrap contribution to total manganese in materials consumed in steelmaking can be estimated as about 38% in 1980 and 40% in 2000. The increase in scrap contribution can be seen as a result of improvements in manganese usage.

Consumption

As shown in Figure 12, reported domestic consumption of manganese as ferroalloys (ferromanganese plus silicomanganese plus metal) has been relatively constant during 1982-2000, after the consumption decline between 1980-82 because of the effect of the large drop in steel production. This is not surprising in view of the offsetting effects of a rising trend in steel production and declining trend in manganese unit consumption in steelmaking. The relatively large drop in unit consumption in steelmaking in the early 1980's is believed to reflect the actual chronology of technological change, coinciding with adoption of such practices as bottom blowing that coincidentally improved the efficiency of manganese use.

Another not unexpected trend is that the share of manganese consumption attributable to ferroalloys has been relatively constant. This simply illustrates that the steel and foundry industries, mostly the former, have continued to account for 85 percent or more of total manganese demand. This also implies that consumption in such non-metallic forms as ore has not changed a great deal. Usage of manganese dioxide for battery applications has shown a healthy growth, but this does not significantly alter the overall usage pattern for manganese materials. Within consumption of manganese ferroalloys, apparent consumption data indicate that the amount of silicomanganese consumed has grown to approach that for ferromanganese. This relates to the growth in electric furnace steelmaking and the preference of electric furnace mills to obtain their manganese units from silicomanganese rather than ferromanganese.

In Figure 14, the flatness of domestic consumption helps explain the negative trend for ferromanganese price. Another factor is the global nature of supply and overcapacity, taking into account such developments as emergence of China as a major producer and a post-Cold War overhang of excess capacity in Ukraine. The market is very competitive even for refined ferromanganese, new capacity for which has been added in several countries in recent years.

Outlook

Major changes in domestic production, consumption, and usage patterns are not foreseen for manganese ferroalloys within the next few years. The course of domestic production depends upon the global strategy of Eramet, owner of the sole domestic plant. Eramet controls a number of smelters in Europe, one of which historically has been a significant supplier of high-carbon ferromanganese to the United States. It seems logical to expect that the emphasis in domestic production will continue to be on refined ferromanganese.

The steel industry will still be the main user of manganese ferroalloys, in proportion to steel production. This assumes that decreases in the amount of manganese used per ton of steel produced have stabilized, and that no technologies are introduced that significantly alter manganese requirements.

Particularly in light of expansions and relatively new projects for production of refined manganese ferroalloys in foreign countries, the market for this sector of the industry is expected to remain highly competitive. This is a condition that will be characteristic for manganese ferroalloys in general.

FERROSILICON
by
Thomas S. Jones

Supply

As indicated by Figure 6, the course of the domestic producing industry was relatively volatile in the 1980's and steady in the 1990's. The number of locations at which silicon ferroalloys were being produced was 14 in 1980 and six in 1999. Production in 1999 was by six companies, only one of which was the same as in 1980. The 1999 producer structure largely had been reached by 1991, after which production of silicon ferroalloys was ended at only three locations. As of the end of January 2000, however, one single-plant company stopped production. During these two decades, a shift in production mix also took place. In 1980, 50% ferrosilicon was the predominant product. As of 1999, 75% ferrosilicon was the silicon ferroalloy being produced in largest quantity; after adjusting for in-plant consumption, the second largest production category was "miscellaneous silicon ferroalloys," which includes magnesium ferrosilicon.

The volume of U.S. ferrosilicon imports during the past two decades showed an irregular rising pattern to more or less a plateau following the imposition of antidumping (AD) duties in 1993-94 on material from Brazil, China, Kazakhstan, Russia, Ukraine, and Venezuela. Following removal of these duties in late 1999, imports rose significantly, especially in 2000. U.S. net import reliance for silicon materials (ferrosilicon and silicon metal) has ranged between 20% and 36% during the period 1985-99, averaging about 30% (35% for ferrosilicon only during 1993-99). In 2000, import reliance rose sharply to the vicinity of 50%. Brazil, Canada, Norway, and

Venezuela have been the leading import sources. Of these, the largest has been Norway, whose share dropped and then rose after AD duties were imposed on other countries, having been in the range of 30% to 50% since 1994. Brazil, whose share was growing, and Venezuela were significant sources before AD duties were levied. Canada's share has steadily declined. U.S. exports of silicon ferroalloys have been considerably smaller than imports. Exports have been relatively constant in the 1990's but larger than during the 1980's.

Except in certain situations where the volume is relatively small, as in production of silicon electrical steel, steel scrap recovery specifically for its silicon content is not practiced. Rather, the return to steel plants of silicon in steel scrap is incidental to the recycling of the iron units in the scrap. The quantity of silicon thus returned can be estimated to exceed that consumed as ferrosilicon, the ratio of the respective amounts being approximately 1.2 for 1980 and 1.5 for 2000. Because silicon in scrap is largely oxidized to the slag as in oxygen steelmaking, the increase of this ratio with time appears to be a consequence of increasing efficiency of use of silicon in steelmaking. At iron foundries, whose principal charge material is scrap, silicon loss also can be high during melting operations.

Consumption

Steelmaking and production of iron castings have been the two main consuming sectors for silicon ferroalloys. Of these, the foundry industry has been the main consumer of silvery pig iron and the miscellaneous silicon ferroalloys. According to the consumption data reported to the former U.S. Bureau of Mines and the U.S. Geological Survey, unit consumption of silicon as a ferroalloy in steelmaking has declined during the past two decades, overall averaging about 1.3 kg per ton (kg/t) of steel. This plus an approximately two-fold increase in consumption of silicon metal have contributed to a declining trend for the share of silicon ferroalloys in overall silicon consumption. In steelmaking, unit consumption of silicon has decreased significantly for 50% ferrosilicon (overall average of 0.5 kg/t) and increased for 75% ferrosilicon (overall average of 0.74 kg/t).

Foundries have been almost as important a market for silicon ferroalloys as the steel industry, having consumed about three-fourths as many silicon units as the steel industry. The most significant trend in consumption by foundries was a decline in use of 50% ferrosilicon, particularly in recent years. While not a ferroalloy, silicon carbide has played an important role in foundry usage by contributing about another 20% toward total silicon consumption. This also has been particularly significant in recent years.

On the whole, current dollar prices for ferrosilicon have advanced at only a modest rate, while showing peaks in 1988 and 1996. Factors suppressing a greater rate of advance have been declining trends in demand and growing foreign competition. The ferrosilicon pricing picture has been complicated by price fixing that domestic producers were alleged or admitted to have done around 1990, and imposition of AD duties that at least temporarily were removed in late 1999.

Outlook

Steelmaking and castings manufacture, for the latter mostly gray and ductile iron, will continue as the main consumers of silicon ferroalloys. For both sectors, the trend line for growth in domestic demand can be estimated as in the 1% to 2% range. A projection by the International Iron and Steel Institute suggests a growth rate for demand by steel that approaches 2%.[1] For iron foundries, trends in the annual growth rates of shipments have been projected at -0.2% for gray iron and 2.4% for ductile iron.[2] This suggests an overall growth rate for castings demand of about 1.0%.

Against this background for demand, the outlook for U.S. producers depends a great deal on the eventual resolution of the application of AD duties, particularly as they apply to Brazil, China, and Venezuela. Domestic producers have been showing a tendency to alter their product mix in favor of specialty and foundry ferrosilicons.

FERROCHROMIUM

by
John F. Papp

Supply

In 1980, world ferrochromium production was 2.86 million tons (metric tons, gross weight). The United States produced 167,000 tons of ferrochromium (by 8 metallurgical companies at 12 plant sites) while importing 219,000 tons. U.S. apparent ferrochromium consumption (low-carbon plus high-carbon ferrochromium production plus imports minus exports) was 358,000 tons. Thus, the United States ferrochromium apparent consumption accounted for about 12.5% of world consumption (as estimated by world production), while U.S. production accounted for 6% of world ferrochromium production and 47% of U.S. ferrochromium apparent consumption. Based on reported (low- plus high-carbon) ferrochromium consumption, usage in stainless steel accounted for 73% of domestic ferrochromium consumption.

In 1998, world ferrochromium production was 4.92 million tons, showing a compounded annual growth rate of 7.01% per year since 1980. The United States produced an undisclosed amount of ferrochromium (by 1 metallurgical company at 1 plant site) while importing 358,000 tons. U.S. apparent ferrochromium consumption (low-carbon plus high-carbon ferrochromium production plus imports minus exports) was 351,000 tons. Thus, the United States ferrochromium apparent consumption accounted for about 7.1% of world consumption (as estimated by world production) while U.S. production was an insignificant part of world ferrochromium production. Based on reported (low- plus high-carbon) ferrochromium consumption, stainless steel accounted for 86% of domestic ferrochromium consumption.

In 1998 compared with that of 1980, the United States produced and consumed less ferrochromium, and the United States consumed a smaller fraction of world production. The fraction of ferrochromium consumed in stainless steel production increased (from 73% to 86%). In other words, while the U.S. ferrochromium production collapsed, the world ferrochromium economy grew. The larger fraction of ferrochromium going into stainless steel resulted from the simultaneous decline in alloy steel production and growth in stainless steel production. Ferrochromium import dependence went from 53% in 1980 to 100% in 1998.

World production and U.S. import dependence changed over the time period. Some of the difference between 1980 and 2000 has to do with political realignments that resulted in the dissolution of the USSR in 1991, the gaining of independence of Eastern European states, and the breakup of Yugoslavia. In 1980, three producing countries accounted for over 50% of ferrochromium production; 12 producing countries, over 90%. In 2000, two producing countries accounted for over 50% of production; nine producing countries, over 90%. These changes show that production was increasingly concentrated over the time period. In fact, the concentration took place mostly as a result of more ferrochromium production in chromite ore-producing countries and lower production in non-chromite ore-producing ones, with the exception of China and Norway. South Africa was the major producer in both years; however, it accounted for 28% in 1980 and 44% in 1998. The changes among major producers, i.e., those comprising the top 90% of production, included the loss of the Brazil, Yugoslavia (and its successor ferrochromium-producing country Macedonia), Germany, the United States, Sweden, and Poland from that group and the addition of India and Norway to that group. All losses except Brazil are non-chromite ore producing countries. Other nations that appear in the top 90% of production have changed position. Japan, a non-chromite ore producing nation, moved down on the list of countries, in descending order of production. Finland, a chromite ore-producing nation, moved up in the list. The anomalies are China and Norway. China produces minor amounts of chromite ore compared to its ferrochromium production, most of which is based on imported ore. China emphasized ferrochromium production when prices surged in 1989. Norway produces ferrochromium because ferrochromium requires electrical energy, a commodity that is relatively inexpensive and available in Norway.

Of the current producers of the top 90% of ferrochromium world production, South Africa, Kazakhstan, India, Zimbabwe, and Finland are major chromite ore-producing countries that base their production on domestic ore supply. China, Russia, Norway, and Japan base their ferrochromium production on imported ore. Ferrochromium production in Japan has been declining since 1980. The ferrochromium industry in Japan, like that of the rest of the world, was based on the presence of a stainless steel-producing industry. As cost of production has risen, mainly labor and electrical power cost, the ferrochromium industry has closed, and Japanese industry has entered joint venture agreements for supply of ferrochromium from South Africa. It is likely that when development occurs in China and Russia, ferrochromium production there too will decline unless major chromite reserves are developed in those countries. Norway is, in effect, using available hydropower to produce ferrochromium. So it is likely to continue ferrochromium production unless higher value added products are developed for its electrical power industry.

Scrap is a major component of stainless steel raw material supply. In 1980, scrap accounted for 47.5% of chromium feed material; in 1998, 52.7%.

Consumption

From 1980-98 the fraction of supply of chromium units for stainless steel production from chromium ferroalloys (that is high- and low-carbon ferrochromium, ferrochromium silicon, and other chromium containing materials) declined from 52.5% to 47.3%; stainless steel scrap captured the difference. Over the same time period, the ratio of chromium in feed material to chromium in raw steel production went from 1.19 to 1.04, indicating increased chromium utilization efficiency. The United States started stainless steel production earlier than many other countries, permitting it to start building a stock of old scrap earlier. As a result, the U.S. stainless steel producers use more scrap for feed material than producers in other countries, and the United States is a major stainless steel scrap exporter.

U.S. chromium ferroalloy consumption increased from 31.8% to 37.4% of U.S. apparent consumption of chromium from 1980 to 1998. This change reflects both the growth of the domestic stainless steel production industry and the shrinkage of other domestic chromium consuming industry. In 1980, there were about 0.175 tons of chromium in chromium ferroalloys (reported consumed for stainless steel production) consumed per ton of chromium in stainless steel produced; in 1998, this figure declined to about 0.130 tons.

The value of ferrochromium increased from 972 dollars per metric ton, contained chromium, in 1980 to 1,009 dollars per metric ton in 1998. These two numbers represent the weighted-average ferrochromium value based on content quantity and declared free-on-board value of U.S. imports as reported in U.S. customs statistics. In dollars adjusted for inflation, the value decreased. Stainless steel cannot be produced without chromium. Thus chromium demand for this use is inflexible. The steel producer can adjust the sources of chromium feed material among scrap, low-carbon ferrochromium, and high-carbon ferrochromium to achieve the most cost effective mix of materials.

Outlook

The past 20 years has seen the demise of the U.S. ferrochromium producing industry. There is no expectation that it will be resurrected in the next 3 years. The domestic stainless steel production industry has seen growth over the past 20 years, as has the world industry; however, the world industry has grown at a faster rate than the U.S. industry. This trend is expected to continue over the next three years. It should be noted that stainless steel production trends, which drive consumption of ferrochromium, show year-on-year changes in production levels that far exceed long-time-period trend changes for ferrochromium consumption.

The distribution of ferrochromium suppliers to the United States has changed over the past 20 years; however, not in the same manner world producers have changed. World chromite ore producers increasingly are ferrochromium producers. South African share of world production increased from 28% in 1980 to 44% in 1998 while South African share of U.S. supply decreased from 73% in 1980 to 37% in 1998. The number of suppliers to the United States increased from 12 to 14 while suppliers of greater than 90% of material increased from 4 to 6 and the composition of that group changed. In 1980, South Africa, Yugoslavia, Zimbabwe, and Sweden accounted for over 90% of imports. In 1998, South Africa, Kazakhstan, Zimbabwe, Turkey, India, and Russia accounted for over 90% of supply. In 1980, Kazakhstan and Russia were part of the U.S.S.R., a country with whom the United States traded relatively little. In 1980, two of the four major suppliers (Yugoslavia and Sweden) used imported chromite ore. In 1998, only one of the major suppliers (Russia) used imported chromite ore.

FERRONICKEL
by
Peter H. Kuck

Supply

The United States has never been self-sufficient in nickel. Imports from Canada, the Caribbean, and Oceania traditionally have satisfied the bulk of U.S. nickel requirements. Since 1992, Russia also has become a major U.S. supplier.

From 1954 to 1988, the Hanna Mining Co. produced ferronickel intermittently at Riddle, OR, from low-grade lateritic ores mined on Nickel Mountain. The original smelter had four melting furnaces and two refining furnaces, with a total annual production capacity of 12,000 tons of Ni in ferronickel. In 1989, Hanna sold the Riddle operation to the Glenbrook Nickel Co. In 1992, Glenbrook upgraded the facility and began processing ore imported from New Caledonia.[3] The New Caledonia ore, supplied by Société Minière du Sud Pacifique (SMSP), averaged 2.3% Ni on a dry basisCsignificantly higher than the 1.0% to 1.25% Ni ore being mined on Nickel Mountain. Glenbrook purchased and rehabilitated a dock at Coos Bay, OR, to receive the wet ore and built a dryer and crushing plant adjacent to the dock to remove as much water as possible prior to calcining. After drying, the ore was hauled in custom-built trucks to Riddle for further processing. The company modernized the smelter=s four 24-megawatt/hour electric arc furnaces, raising the capacity of the complex to 16,000 tons per year Ni, and constructed a shot casting facility next to the furnace building. Ferronickel now could be produced in two forms: 12.7-kilogram ingots and minus 6-millimeter shot.

The ferronickel produced at Riddle had to compete directly against ferronickel from Colombia (46% Ni), the Dominican Republic (38% Ni), and New Caledonia (28% Ni). The Riddle plant relied on the Ugine reduction process to extract the nickel from the molten lateritic ore. The process used ferrosilicon as a reductant and produced a high nickel-grade of ferronickelC49% to 51% Ni. When world nickel prices began to weaken in 1997, Cominco decided to permanently close the Riddle operation. The last day of operation was March 30, 1998. By then, ore reserves on Nickel Mountain had dwindled to 230,000 tons grading 1.25% Ni.[4] Additional resources of similar grade were available at other laterite deposits in the Klamath Mountains, which extend from southwestern Oregon into northern California, but trucking low-grade ore from these isolated and scattered pockets would not have been profitable at 1998-2000 nickel prices.

Many of Glenbrook=s customers were unwilling to pay a premium to offset the costs of using ferrosilicon and found that lower-grades of imported ferronickel worked equally well in most situations. Glenbrook initially used inexpensive ferrosilicon imported from Kazakhstan, but decided to make its own ferrosilicon after the U.S. International Trade Commission and Department of Commerce imposed anti-dumping duties in 1992 on ferrosilicon imported from Kazakhstan and several other countries. The cost of ferrosilicon remained a major expense for Glenbrook until closure, even though the facility had a dedicated 15-megavolt-ampere furnace capable of producing 20,000 tons per year of 50% ferrosilicon. The Riddle operation had one advantage over several of its competitorsCrelatively inexpensive electric power. Part of the ferrosilicon production cost was offset by a favorable hydroelectric power contract with the Bonneville Power Administration. The power contract would not have expired until October 1, 2001.

For almost 40 years, Federal regulations have prohibited the importation of Cuban nickel into the United States. At some point in time, though, the U.S. embargo could be lifted, drastically changing nickel supply patterns in the Western Hemisphere. The lifting of the embargo probably would be linked to settlement of ownership claims on the Moa and Nicaro nickel plants. The Cuban Government expropriated the two plants in 1960 and, with Soviet help, built a third plant at Punta Gorda in 1987. This third plant was modeled after Nicaro and, like Nicaro, employed ammonia leaching.

Consumption

Nickel content in excess of 8% is needed to produce the austenitic structure in 300-series stainless steels. The nickel content of some austenitic grades can be as high as 22%. Duplex (ferritic-austenitic) steels generally contain only 2.5% to 5.0% Ni. Smaller amounts of nickel (0.2% to 3.8%) sometimes are incorporated into low alloy steels to improve their resistance to atmospheric corrosion. Stainless steel accounts for more than 60% of nickel consumption in the world. In the United States, however, this percentage is considerably lower and is closer to 40% because of the relatively large number of specialty metal industries in the country. Specialty uses include superalloys and other aerospace alloys, high-temperature nickel-chromium alloys, electrolytic plating, electroless plating, cupronickel alloys, and naval brasses.

More than 98% of the ferronickel consumed in the United States is used in the manufacture of stainless steel or alloy steel. The nickel content of imported ferronickel typically ranges from 27% to 46% Ni, although some Indonesian and Japanese products being sold to foreign consumers contain as little as 17.5% Ni. The ferroalloy is sometimes used as an addition agent to make copper alloys, but is rarely used in superalloy or nickel-base alloy production. In many steelmaking situations, ferronickel can be replaced by nickel cathode, nickel briquets, nickel oxide sinter, chromium-nickel remelt alloy, or good quality nickel-bearing scrap. Differences in price premiums and ease of availability are important factors to consider.

Utility nickel and other metallic nickel additions produced from nickel oxide typically contain from 92.0 to 98.5% Ni, while the nickel content of oxide sinter can be as low as 75%. Nickel oxide is easily reduced during steelmaking.[5] The ease of substitution in steelmaking helps to explain the significant shifts in ferronickel consumed (per ton of steel) that took place between 1979 and 1991Ca time when skyrocketing energy costs, high labor costs, new technology, competition from overseas producers, etc. triggered a massive restructuring of the steel industry in the United States and Canada. Between January 1987 and April 1988, the monthly LME cash price for cut cathode and briquets rose dramatically from $3,526 per ton to $18,012 per ton, and then gradually dropped back below $5,000 per ton over the next 5 years. Several factors reportedly contributed to the price spike of 1988-90. (1) Demand for austenitic stainless steel in the Western World rose 30% between 1986 and 1988, outstripping existing nickel production capacity. (2) Nickel producers were forced to close EXMIBAL and several other nickel mines between 1980 and 1986 because of low nickel prices and escalating costs of fuel oil and gasoline. (3) The low nickel prices of 1983-86 also discouraged scrap brokers and processors from building up stocks, creating a scrap shortage when stainless steel production accelerated in 1988. (4) In December 1987, the Government of the Dominican Republic imposed a 25% export duty on ferronickel. Falconbridge Dominicana C. por. A., the only

producer on the island, responded by halting shipments of ferronickel and declaring *force majeure*. To counter these shortages, U.S. stainless steel producers began to increasingly substitute cathode and nickel oxide for ferronickel and scrap.
In the United States, changes in demand in sectors other than steelmaking can cause changes in price premiums for the less common grades of nickel. For example, in late 1999, a labor dispute at Inco Limited=s smelting and refining complex in Thompson, Manitoba, created a shortage of plating-grade nickel in the United States at a time when the Western World supply of cathode and ferronickel was only slightly less than demand.[6,7,8] After Inco declared *force majeure* on some of its products in November 1999, the Ryan=s Notes plating premium (a monthly average) increased from 18-21 cents per pound to 22-25 cents and eventually peaked at 25-29 cents in February 2000.

Outlook

For the near future, there is little chance for a revival of ferronickel production in the United States. The startup of a greenfield ferronickel operation in Venezuela and the expansion of existing capacity in Colombia, Indonesia, and New Caledonia have discouraged potential ferronickel producers from building facilities in the United States. The use of high pressure acid leaching (PAL) technology to recover nickel from lateritic ores in Western Australia is expected to keep nickel prices in check for at least a decade. The combined rate of refined nickel production for the three existing Australian PAL operations is expected to pass 9,000 tons per year at the beginning of 2001 and keep growing for at least another 3 years, eventually surpassing 100,000 tons per year. Plans to develop additional lateritic nickel deposits in the Kalgoorlie region have accelerated since the Goldfields natural gas pipeline was completed in late 1996.[9] The availability of inexpensive natural gas from offshore fields on the North West Shelf of the Indian Ocean has made it economically possible to produce refined nickel at several other laterite deposits previously rejected because of their remote locations. The immense resources of the Voisey=s Bay nickel-copper-cobalt deposit in northeastern Labrador also continue to overhang the market. Inco and the Provincial Government of Newfoundland could reach an agreement at any time on developing the sub-Arctic deposit. Depending upon market conditions, the proposed Voisey=s Bay mining and milling complex would be capable of producing from 60,000 to 123,000 tons per year of nickel in sulfide concentrates. In Ontario, Inco continues to find new ore along the edges of the Sudbury Basin. At least part of the new production from Cerro Matoso (Colombia) and Loma de Níquel (Venezuela) is expected to come to the United States. In 1996, SMSP and Falconbridge Limited formed a partnership to build a ferronickel smelter in the North Province of New Caledonia. The smelter is being designed to produce 54,000 tons per year of nickel in ferronickel. The joint venture and SLN=s expansion of existing smelting capacity at Doniambo would put additional material into the U.S. supply line. Inco also is considering constructing a full-scale PAL plant at Goro, southeast of Doniambo.

Changes in North American politics could lead to a significant increase in Cuban nickel production. Billiton and the Government of Cuba have formed a joint venture to evaluate the San Felipe laterite deposits in Camaguey Province. Initial work indicates that the San Felipe deposits contain some 200 to 250 million dry tons of resources grading more than 1.3% Ni. The lateritic ore reportedly is amenable to pressure acid leaching. QNI, the Australian subsidiary of Billiton, has a 65% interest in the venture. The remaining 35% is controlled by Geominera S.A., a Cuban parastatal company responsible for nonferrous metal exploration.

The outlook for stainless steel production in the United States is positive. Stainless steel production in the United States could exceed 2.6 million tons in 2000—an all time record high for the country. The austenitic share of the production is expected to remain unchanged at 63%. This percentage is lower than corresponding austenitic percentages reported by other Organization for Economic Cooperation and Development (OECD) countries because the U.S. motor vehicle manufacturing industry, which consumes more than 420,000 tons of non-nickel bearing ferritic stainless annually, comprises a larger share of the stainless steel market than in most other OECD countries.

Surprisingly, the United States has significant potential for increased consumption of stainless steel, relative to other industrialized countries. Per-capita consumption of stainless steel in the United States is currently less than one-half that in such countries as Italy, Japan, the Republic of Korea, and Taiwan. U.S. industry is finding that it is cost effective to fabricate critical parts, machinery, and plumbing fixtures from stainless steel, or even superalloys, despite the higher prices of these materials. The downtime, high-labor costs, and customer ill will incurred in replacing less expensive materials that have corroded or cracked far outweigh the initial cost of using more durable nickel alloys. Use in the construction industry is also growing. For example, stainless steel sheet is being used more for roofing and paneling in commercial buildings. Revolutionary aerospace stiffeners are now being used to attach stainless steel panels to precast concrete walls.[10]

FERROMOLYBDENUM
by
John W. Blossom

Supply

Four United States companies in 1999 produced 4.7 percent of the U.S. ferromolybdenum supply, excluding stocks; imports from three countries accounted for the remaining 95.3 percent. Suppliers of imports were China, Canada, and the United Kingdom. The United States exported 17 percent of the U.S. ferromolybdenum supply to seven countries, and consumed the remainder.[11]

The production of ferromolybdenum is a straightforward thermite process. The typical mixture consists of molybdenum oxide, aluminum, ferrosilicon, iron, lime, and fluorspar. These components are mixed together and charged into bottomless bricklined steel shells which have previously been placed over a shallow pit scooped in damp sand. The pot is banked with sand and a dust hood placed into position. The reaction is started by igniting the charge. Melting takes about 20 minutes. The mass is left for a few hours to allow the metal to solidify and cool. The skull of sintered sand is knocked off and the slag is then broken off from the surface. The metal button is quenched with water. This quenching operation not only cools the metal but also facilitates breaking the mass into pieces suitable for handling. The process is not complicated but it is labor intensive.[12,13]

Consumption

The principal use of ferromolybdenum is to adjust the amount of molybdenum in steel melt to obtain the prescribed amount of molybdenum. The form of molybdenum used in making cast and wrought steels depends largely on the steelmaking process, on local conditions, and on the percentage of molybdenum to be added. Ferromolybdenum is adaptable to any of the processes. Molybdenum oxide is often used because it is cheaper. From the standpoint of close control and uniformity of composition, it is preferable to add molybdenum in the furnace. In steel foundries, however, it is often desired to add molybdenum to only a portion of a heat; in such cases, it is feasible to add up to 0.5 percent molybdenum, in the form of ferromolybdenum, to the ladle.[12]

The major use for molybdenum is in the manufacture of alloy steel, and more than 70 percent of the molybdenum produced has been applied to this purpose; 22 percent of this amount is in the form of ferromolybdenum and calcium molybdate. The principal advantages are improved hardenability, reduction of mass effect, increase in toughness, the avoidance of temper-brittleness, and the maintenance of high temperature properties.[12] Molybdenum in ferromolybdenum per ton of alloy and stainless steel production has been trending upward at 6.3 percent per year on average (1980-2000).

The ferromolybdenum price is affected by the availability of molybdenum oxide and ferromolybdenum on the world market, which has been in oversupply worldwide. Consequently, the United States dollar price for ferromolybdenum since 1980 has trended downward, 11.1 percent per year on average.

Outlook

Because of abundant resources and adequate production capacity in the United States, China, Chile, and other countries, the future requirement for ferromolybdenum should be readily met by the world producers. The principal use for ferromolybdenum will continue to be as an additive in steel manufacturing in general, most importantly alloy and stainless steel. Strong growth in production of stainless steel and superalloys can be expected in the near term with generally healthy economic conditions over the next few years.

FERROVANADIUM

by

Robert G. Reese

Supply

Ferrovanadium, a ferroalloy produced through the reduction of vanadium pentoxide by various metallurgical processes, is used for adding vanadium to steel to increase its hardness, ductility, and toughness. The United States relies on three sources for its vanadium supply—domestic mining activity, other raw materials with significant vanadium content, and imports.

Although relatively abundant, vanadium rarely occurs in deposits that can be economically exploited solely for the contained vanadium. Owing to its affinity for oxygen and other gases, vanadium is usually recovered as vanadium pentoxide. Historically, the United States has produced vanadium pentoxide as either a byproduct or co-product of mining vanadiferous clays in Arkansas, phosphate in Idaho and Wyoming, and uranium in Colorado and Utah. As a result, domestic mine production of vanadium is dependent on the market for the other material. At present, domestic mine production of vanadium pentoxide is limited to one phosphate mine in Idaho.

The United States produces a significant amount of vanadium pentoxide by processing other raw materials. These materials are the products of several waste streams in which the contained vanadium is concentrated to a sufficient degree to allow for economic extraction. They include both domestically generated and imported fly ash, slags from steel production, and petroleum residues.

The remaining major source of vanadium for the domestic economy is imported vanadium pentoxide and ferrovanadium. The major sources for domestic pentoxide imports are South Africa and China. During the period 1995-98, these two countries have supplied 94% and 5% of the U.S.'s requirements for vanadium pentoxide. Sources for ferrovanadium imports are more diversified. For 1995-98, Canada (47%), China (15%), the Czech Republic (12%), and South Africa (11%) were the most important sources.

Although U.S. ferrovanadium production is not reported because reporting is not mandatory, it is believed that fewer than 10 domestic companies produce ferrovanadium. Based on consumption data and net imports of ferrovanadium, it is estimated that domestic ferrovanadium production in 1998 was about 3,000 t. During the period 1980-97, similar estimates have averaged approximately 3,200 t, and production has trended downward about 2.7% per year as shown in Figure 7.

Consumption

Although vanadium has many uses, metallurgical applications account for essentially all domestic consumption. Total vanadium consumption was 4,390 metric tons (t) in 1998, most of which (91%) was in the form of ferrovanadium (4,010 t). Of the total 4,390 t, various steel end uses accounted for 3,800 t, with the major uses being carbon steel (1,650 t), high-strength low-alloy steel (950 t), and full alloy steel (891 t).[14] The only other significant consumption of vanadium in 1998 was 508 t for the production of alloys other than steel and superalloys.

Outlook

Since the dominant use for ferrovanadium is as an additive to steel, the steel industry will be the primary factor influencing ferrovanadium demand. Although the steel industry is cyclical, it is believed that long-term ferrovanadium demand will grow slightly, owing primarily to the growing need for stronger and lighter steels. Regarding the domestic vanadium supply, the resumption of large-scale domestic mining activity is unlikely. Recent development of low-cost foreign deposits should, baring unforeseen events, preclude reopening domestic mines. As a result, the United States will rely on imports and the processing of other raw materials to supply the vanadium needed for its steel industry. Although environmental concerns are likely to lead to increased vanadium recovery from various waste streams, increased foreign processing capacity will result in more imports of ferrovanadium.

FERROTITANIUM
by
Joseph Gambogi

Supply

On a gross weight basis, world ferrotitanium production capacity is estimated to be 64,000 metric tons, led by the United Kingdom, Russia, Japan, and the United States.[15] U.S. producers of ferrotitanium are Global Titanium, Inc. (Detroit, MI), Shieldalloy Metallurgical Corp. (Newfield, NJ), and Galt Alloys Inc. (North Canton, OH). In addition to domestic producers, numerous companies are involved in the importation and trade of ferrotitanium.

Prior to the advent of clean scrap metal from the titanium metal industry, ferrotitanium was produced by aluminothermic reduction of ilmenite. At that time, 30%-40% grade ferrotitanium was produced as an additive to stainless steels. Ferrotitanium is now produced in grades ranging from 25% to 75% titanium content; however, in the United States and much of the world, production is based primarily on the 75% grade. Production methods are based on induction melting of scrap metal or in some cases titanium sponge metal.[16]

The supply of ferrotitanium is greatly influenced by the price and availability of titanium scrap and sponge. The primary source of scrap is that generated during the fabrication of titanium mill shapes. Because the production of titanium metal is highly cyclic, so is the generation of scrap. This has had a dramatic effect on the price and availability of ferrotitanium. For example, in 1997 titanium metal was produced at a record level. The excess scrap generated during this production peak contributed to a 36% decrease in ferrotitanium prices.

During the 1990's, imports played a major role in the supply of ferrotitanium to the United States. The dissolution of the Soviet Union in 1991 made large supplies of sponge and scrap available to the open market. Scrap imports began to increase in 1992, but an antidumping duty on titanium sponge limited the volume of imports. By 1993, former Soviet Union (FSU) and European producers found that high-quality ferrotitanium could be produced from FSU sponge and scrap at competitive prices. From 1992 to 1993, annual imports of ferrotitanium increased from 1,357 tons (gross weight) to 4,843 tons (gross weight) , a 257% increase. The yearend published price of ferrotitanium in 1993 decreased 19% compared with that of 1992. Ferrotitanium imports have decreased somewhat from the peak of 7,724 tons (gross weight) in 1997, but continue to play a dominant role in the supply of ferrotitanium.

Consumption

Global consumption of ferrotitanium is estimated to be 30,000 tons (gross weight) per year and is led by Germany, France, Italy, Japan, Scandinavia, and United States.[17] According to survey data, ferrotitanium consumption in the United States was about 3,600 tons (contained weight). Since 1985, consumption has increased 4% annually.

Ferrotitanium is used in steel for deoxidation, grain size control, and control and stabilization of carbon and nitrogen. The addition of titanium to steel is made in the ladle and is in form of ferrotitanium, ferrosilicon-titanium, scrap, or sponge.[18]

On a technical basis, ferrotitanium is usually preferred over titanium scrap or sponge. Ferrotitanium has a lower melting point and has a higher density than scrap. Consequently, ferrotitanium is more readily dissolved in molten metal. Another advantage of ferrotitanium over scrap is the ability to control chemistry and size.[15] Ferrosilicon-titanium is used to permit simultaneous addition of silicon and titanium, usually in equal amounts.

Recent consumption trends have been led by the production of stainless steel, boron hardened steel, high strength, low alloy (HSLA) hot rolled strip, interstitial free (IF) steels, low carbon steel, and microalloyed steel.[19]

Outlook

Growth in the consumption of ultra low carbon steels for automotive applications and appliances are expected to increase demand for ferrotitanium. Given that the long-term growth trend for ferrotitanium imports has been about 19% per year, imports are expected to meet much of the future domestic demand for ferrotitanium. New sponge capacity in the Ukraine is expected to help supply European producers of ferrotitanium.

FERRONIOBIUM
by
Larry D. Cunningham

Supply

The United States does not have a niobium mining industry and must import all of its niobium source materials for processing, mostly niobium-bearing materials from Africa, Australia, and China. Brazil and Canada are the world's largest producers of niobium pyrochlore, the niobium source material used to produce steelmaking-grade ferroniobium, together accounting for more than 95% of total reported world production. Brazil discontinued the export of pyrochlore in 1981 and now exports only upgraded/value added niobium products, mostly steelmaking-grade ferroniobium. Prior to 1994, the United States converted pyrochlore from Canada into steelmaking-grade ferroniobium. However, starting in late 1994, all pyrochlore produced in Canada was being converted to steelmaking-grade ferroniobium in that country. Four U.S. companies produce ferroniobium from intermediate niobium products, but production is of the high-purity grade used for superalloy manufacture. Thus, there basically is no U.S. production of steelmaking-grade ferroniobium, and the U.S. steel industry requirements for ferroniobium are virtually satisfied entirely by imports.[20]

Brazil is the leading producer of ferroniobium for steelmaking, with an annual production capacity of more than 20,000 metric tons of contained niobium, with planned expansion to increase capacity to more than 30,000 tons. Canada's annual capacity to produce ferroniobium for steelmaking is about 2,200 tons of contained niobium. The United States currently imports annually from Brazil about 4,000 tons of niobium contained in ferroniobium, mostly steelmaking-grade, and about 400 tons of niobium contained in steelmaking-grade ferroniobium from Canada.

Ferroniobium supply has also been aided by sales from the U.S. Government's National Defense Stockpile (NDS). Ferroniobium sales began in March 1997, and, about that time, the NDS held about 530 tons of niobium contained in ferroniobium, mainly steelmaking-grade material. The majority of the stockpiled ferroniobium has since been sold, with the NDS Manager having disposal authority for the remaining material.

It is estimated that less than 10% of steel produced in the world benefits from the advantages of niobium addition, with most niobium-bearing steels containing less than 0.1% niobium.[21] While niobium is not recovered from scrap steel containing it, recycling of scrap steel is significant, and niobium content where applicable can be reutilized. Much of the niobium recycled in steel is diluted to nominal levels but tolerated, effectively becoming a substitute for iron or other alloy metals rather than being used for its unique properties, or it is oxidized and removed in processing.

Consumption

The principal use for niobium, in the form of steelmaking-grade ferroniobium, is as an additive in steelmaking to improve strength and corrosion resistance characteristics. Also, appreciable amounts of niobium, in the form of high-purity grade ferroniobium, are used in nickel- and cobalt-based superalloys for applications such as jet engine components such as turbine blades and vanes. Ferroniobium is typically available in grades containing from 60% to 70% niobium. The United States currently consumes about 3,900 tons of niobium, including about 3,200 tons of niobium contained in ferroniobium of which about 2,800 tons is in the form of steelmaking-grade ferroniobium. The amount of niobium consumed as ferroniobium currently accounts for about 80% of total U.S. niobium demand and has increased by a total of about 22% since 1980, a growth rate trend of less than 1% per year based on consumption in 1980 and 2000. For the same period, niobium consumed as ferroniobium in steelmaking has increased by about 35% and accounts for more than 70% of total U.S. niobium consumption. Based on U.S. reported ferroniobium consumption data, the amount of niobium consumed per ton of steel produced (including non-niobium containing steels) has increased by more than 25% since 1980, a unit consumption growth rate trend of about 1.6% per year. In the automobile industry, the use/amount of high-strength niobium-containing steel has continued to increase despite the trend to reduce the total amount of steel in automobiles. While most niobium-bearing steels contain less than 0.1% niobium, some stainless steels can contain as much as 1.25% niobium. (See table 2). The most important niobium-containing superalloy, nickel-base alloy Inconel 718, contains about 5% niobium.

The ferroniobium price is affected most by the availability of pyrochlore and the capacity to convert this material to steelmaking-grade ferroniobium. As the dominant producer/supplier of ferroniobium since the mid to late 1960's, Brazil has maintained a marketing strategy of stable supply and moderate price changes. As mentioned, the demand for steelmaking-grade ferroniobium since 1980 has increased a total of about 35%, while the price has increased a total of less than 10%. In terms of constant dollars, the price has actually declined by more than 40%, or 2.8% per year on average, mostly a function of readily available ferroniobium supply.

Outlook

The nonavailability of pyrochlore minerals from Brazil and Canada for U.S. processing dictates that future requirements of steelmaking-grade ferroniobium from the domestic steel industry will be met almost entirely with imports. Brazil will continue as the leading source for U.S. imports of steelmaking-grade ferroniobium, and Canada will also be a major source of supply. Most of the U.S. requirements for high-purity grade ferroniobium will continue to be met by domestic production.

The principal use for ferroniobium will continue as an additive in steelmaking, mostly in the manufacture of microalloyed steels used for pipelines, bridges, automobiles, etc. The trend of U.S. niobium demand will continue to follow closely that of domestic steel production. The production of high-strength low-alloy steel is the leading use for steelmaking-grade ferroniobium, and the close relationship between steel production and niobium consumption is expected to continue. Superalloy manufacture, the second largest use for ferroniobium, will be most dependent on the market for aircraft engines. Nickel-base superalloys (in particular alloy 718), which can account for about 40% to 50% of engine weight, are expected to be the materials of choice for the future owing to their high-temperature operating capability.

FERROTUNGSTEN

by

Larry D. Cunningham and Kim B. Shedd

Supply

There has been no recorded U.S. tungsten concentrate production since 1994. Prior to 1999, when the U.S. Government began selling tungsten materials from the National Defense Stockpile (NDS), the United States imported all of its tungsten mineral concentrates, mostly from Bolivia, Kazakhstan, Portugal, and Russia. The imported and NDS concentrates and tungsten-bearing scrap are processed into ammonium paratungstate, tungsten oxide, tungsten powder, tungsten carbide powder, and/or tungsten chemicals. There has been no reported U.S. production of ferrotungsten since the late 1980's, and until 1999, the United States imported most of its ferrotungsten requirements. U.S. ferrotungsten imports, less than 700 metric tons of contained tungsten in 1999, came mostly from China (over 74%) and Russia (about 25%). Ferrotungsten generally accounts for less than 10% of total U.S. tungsten imports.

China is the leading producer of tungsten mineral concentrate, currently accounting for more than 75% of total estimated world mine production. Prior to 1985, tungsten mine production in China was dominated by state mines. However, with promotion of private production, China's current output from private tungsten mines reportedly is at a level double that from state mines.[22] However, most tungsten exports from China are in processed forms, including ferrotungsten, in lieu of tungsten concentrates. China's ferrotungsten production is said to account for an estimated 90% of total world production.[23] In recent years, ferrotungsten from stockpiles in China, Kazakhstan, Russia, and Ukraine also has been a significant source of world supply.[23] In the first half of 1999, to combat oversupply and the excessive waste of resources, the Chinese government banned the issuance of new tungsten mining permits and reduced the number of export licenses for tungsten materials.[24]

In August 1999, the U.S. Government initiated the sale of ferrotungsten from the National Defense Stockpile (NDS). At that time, the NDS held approximately 918 tons of tungsten contained in ferrotungsten, all of which was authorized for eventual disposal. The minimum amount of ferrotungsten that could be sold during the fiscal year, part of the Annual Materials Plan, was set at 136 tons for the fiscal year beginning October 1, 1998[25] and was maintained at the same level for the following 2 fiscal years.

Certain alloy, stainless and heat-resisting, and tool steels can contain up to about 21% tungsten. (See table 2.) Of the tungsten recycled from this end-use sector, scrap is returned to the steel industry with consequent dilution of the contained tungsten in new steel production.[26]

Consumption

The main use for tungsten in the United States is in the form of tungsten carbide powders for the manufacture of cemented carbide parts to be used as cutting and wear-resistant materials primarily in the metalworking, oil and gas drilling, mining, and construction industries. This use accounts for more than 70% of total U.S. annual tungsten demand. Tungsten also is consumed by the steel industry, accounting for about 5% of total U.S. demand. Tungsten's use in this sector is mainly in the production of tool steels, and, to a minor degree, in certain grades of alloy, and stainless and heat-resisting steels. Tungsten is supplied to the steel industry in the form of ferrotungsten in grades containing from 75% to 80% tungsten, as natural or synthetic scheelite ($CaWO_4$) containing 55% to 70% tungsten, as tungsten melting base containing up to 36% tungsten, and as tungsten metal scrap containing 90% to 98% tungsten from the lighting (filament) industry. The choice of the alloying agent is largely determined by the steelmaking practice, product requirements, and economics.[27,28,29]

Current (2000) annual consumption of tungsten in the United States is estimated at about 14,700 metric tons. On the basis of data reported by industry to the U.S. Geological Survey, approximately 500 tons of tungsten is consumed in the form of ferrotungsten, mostly in steelmaking. The tungsten contained in ferrotungsten consumed as a percentage of total tungsten consumption has experienced a growth rate trend of about 5.5% per year since 1980. For the same period, the amount of tungsten consumed as ferrotungsten has increased by more than 140%, a growth rate trend of about 7% per year. Also, the amount of tungsten consumed per ton of alloy steel produced (including many non-tungsten containing alloys) has increased substantially since 1980, with a unit consumption growth rate trend of more than 10% per year.

The ferrotungsten price is affected most by the price for tungsten concentrates, which historically has fluctuated in response to either scarcity or oversupply. Some of the variables that have influenced the irregular tungsten price cycles include China's position as the world's largest producer, material availability from Communist or former Communist countries, buildup or reduction in various Government stockpiles and industry inventories, and production fluctuations.[30] Since 1985, the current dollar price for ferrotungsten has decreased by a total of about 30%, a decline of 3.8% per year on average in terms of constant dollars.

Outlook

Future ferrotungsten requirements from the domestic steel industry will be met primarily by imports and sales from the NDS. China will continue as the dominant producer/exporter of tungsten products and the leading source of U.S. ferrotungsten supply. Approximately one-quarter of the world's tungsten supply comes from various Government stockpiles, while world tungsten mine capacity is estimated to be less than demand. As these stockpiles are depleted, mine production will have to be increased in order to meet future tungsten demand.[24]

Cemented carbides will continue as the major end-use for tungsten and future demand will be dependent on the performance of the automotive, aircraft, construction, oil and gas drilling, and mining industries. U.S. tungsten consumption, in the form of ferrotungsten, is expected to remain at less than 10% of total demand. Demand will continue to come mostly from the domestic steel industry, in the production of tool steels, and the health of this end-use sector will dictate future U.S. consumption of ferrotungsten.

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