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U.S. GEOLOGICAL SURVEY

COLUMBIUM (NIOBIUM) RECYCLING IN THE UNITED STATES IN 1998

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ABSTRACT

This report describes the flow of columbium in the United States in 1998 with emphasis on the extent to which columbium (niobium) was recycled/reused. Columbium was mostly recycled from products of columbium-bearing steels and superalloys; little was recovered from products specifically for their columbium content. In 1998, about 1,800 metric tons of columbium was recycled/reused, with about 55% derived from old scrap. The columbium recycling rate was calculated to be 22%, and columbium scrap recycling efficiency, 50%.

INTRODUCTION

This materials flow study of columbium, as shown in figure 1, includes a description of columbium supply and demand factors for the United States in 1998 in order to illustrate the extent of columbium recycling to identify recycling trends.

Columbium [niobium (Nb)] is a steel-gray ductile refractory metal that is used mostly as an alloying element in steels and superalloys. Columbium and niobium are synonymous names for the chemical element with atomic number 41—columbium was the name given in 1801, and niobium was the name officially designated by the International Union of Pure and Applied Chemistry in 1950. The metal conducts heat and electricity relatively well, has a high melting point (about 2,470 °C), is readily fabricated, and is highly resistant to many chemical environments.

Salient columbium statistics are based on the columbium content of steel and superalloy scrap (table 1). In 1998, about 2,900 metric tons (t) of columbium contained in old scrap was generated, with about 1,000 t of columbium valued at about $15 million recycled/reused. The old scrap recycling efficiency was calculated to be about 50%, and the recycling rate was about 22%. Columbium contained in new scrap consumed was about 800 t. (See Appendix for definitions.)

GLOBAL GEOLOGIC OCCURRENCE OF COLUMBIUM

Columbium is almost always found in nature as an oxide in association with other minerals, but not in elemental form or as a sulfide. Columbium has an overall crustal abundance estimated to be 20 parts per million and a strong geochemical coherence with tantalum. Pyrochlore [$(Ca,Na)_2Nb_2(O,OH,F)_7$] and bariopyrochlore (also known as pandaite), which is its barium analog, from Brazil and Canada have become the main sources of columbium. The minerals, which contain little tantalum, have a columbium oxide-to-tantalum oxide ratio of 200:1 or greater. The minerals are commonly found in the interior parts of alkaline igneous complexes, frequently in association with minerals of thorium, titanium, uranium, and rare-earth elements. In Brazil, the occurrences are in eluvial deposits that result from the weathering in place of carbonatites, which leaves an enriched concentration of apatite, bariopyrochlore, and magnetite. In Canada, the occurrences are in complex ring structures of carbonatite and alkaline rocks in the Precambrian Shield. Columbite and tantalite, which are similar in chemical composition and atomic structure, are the other principal columbium minerals. The proper name for the mineral is columbite when columbium predominates over tantalum; when the reverse is true, the proper name is tantalite. Columbite-tantalite, which is also known as coltan in some African countries, occurs mainly as an accessory mineral disseminated in granitic rocks or in pegmatites associated with granites. Columbite-tantalite is known to exist in all continents, but most deposits with relatively high columbium or tantalum content are small and erratically distributed. In most cases, economic mineral concentrations have been produced by weathering of pegmatites and formation of residual or placer deposits (Parker and Adams, 1973; Cunningham, 1985; Crockett and Sutphin, 1993, p. 6-7).

The largest columbium reserves and resources are located in Brazil, where reserves are estimated to be more than 3 million metric tons of contained columbium in pyrochlore deposits. Canada has the second largest columbium reserves in pyrochlore deposits; the reserves are estimated to be about 140,000 t of contained columbium (Cunningham, 2001). U.S. columbium resources are of low grade, and none were considered economically minable in 1998.

PRODUCTION AND PRODUCTION PROCESSES

The United States, which has no columbium mining industry, must import all its columbium source materials for processing. Brazil and Canada, which are the world's largest producers of columbium minerals (pyrochlore), together account for more than 95% of total

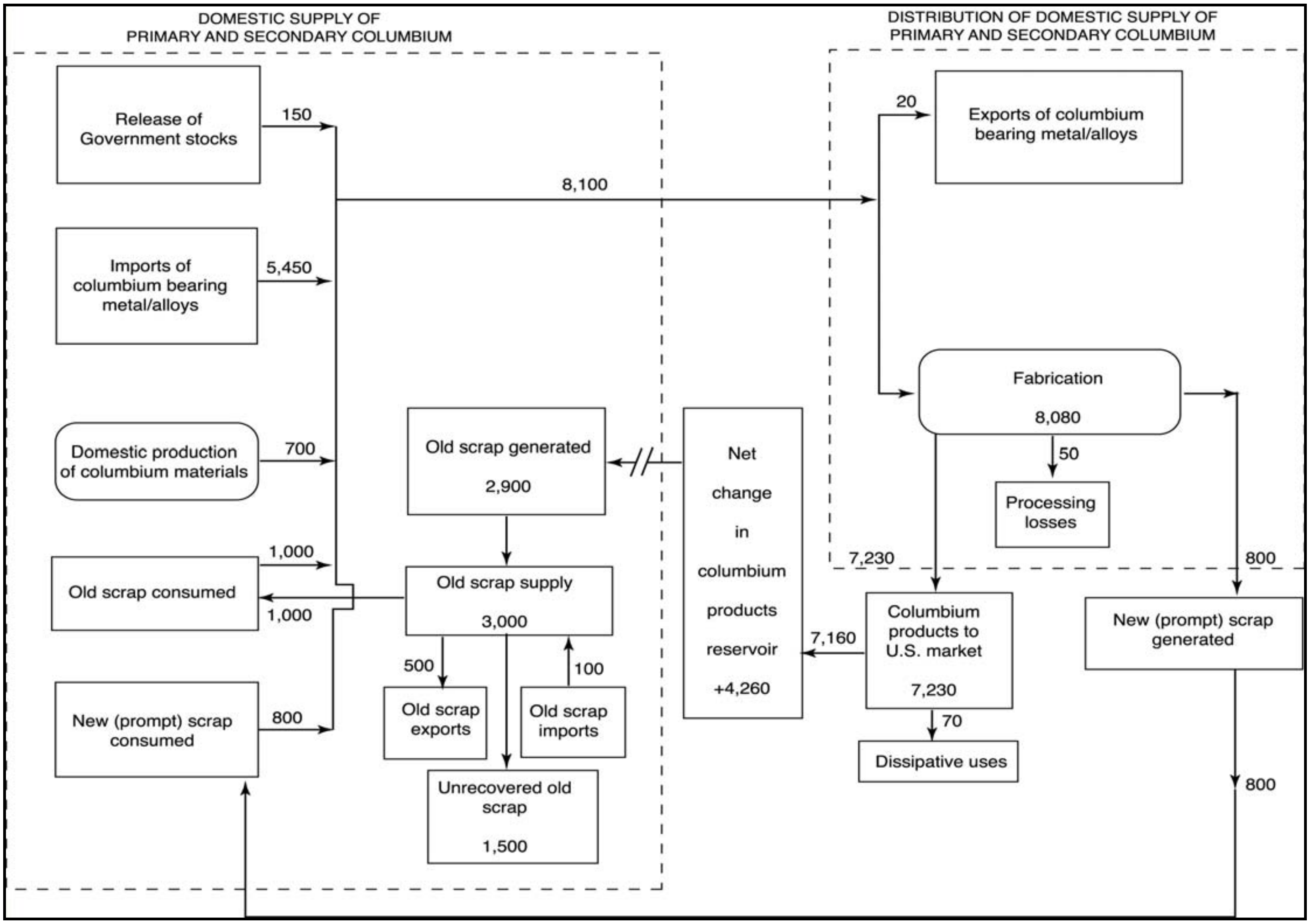

Figure 1. U.S. columbium recycling flow, 1998, in metric tons contained columbium.

reported world production. Pyrochlore is the columbium source material that is used to produce steelmaking-grade ferrocolumbium. The remaining columbium mineral supply comes from the mining of columbite and columbite-tantalite mostly in Australia, Brazil, Nigeria, and other African countries. Brazil discontinued the export of pyrochlore about 1981 and now exports only upgraded/value-added columbium products, mostly steelmaking-grade ferrocolumbium. Prior to 1994, the United States converted pyrochlore from Canada into steelmaking-grade ferrocolumbium. Starting in late 1994, however, all pyrochlore produced in Canada was being converted to steelmaking-grade ferrocolumbium in that country. Thus, the United States does not produce steelmaking-grade ferrocolumbium from pyrochlore, and the U.S. steel industry requirements for ferrocolumbium are satisfied virtually entirely by imports. Brazil's annual ferrocolumbium production capacity, mostly steelmaking-grade, is more than 30,000 t of contained columbium. In 1998, Brazil accounted for almost 80% of total U.S columbium imports. Canada's annual capacity is about 2,200 t of contained columbium in steelmaking-grade ferrocolumbium.

Pyrochlore is mined mainly by mechanized open pit or underground methods. Mining for pyrochlore in Brazil is open pit, whereas an underground mining method is used in Canada. Ore with host rock is usually dislodged from a working face with explosives. After the ore has been finely ground, beneficiation is achieved primarily by various flotation procedures combined with magnetic separation to remove iron minerals. A chloridizing and leaching process also can be used to lower barium, lead, phosphorus, and sulfur contents. Methods used to mine other columbium-bearing ores have ranged from simple hand operations in small pegmatite mines to hydraulic monitors and dredges at placer deposits. Aluminothermy is a process used for making steelmaking-grade ferrocolumbium from pyrochlore concentrates. A mixed charge of pyrochlore concentrates, iron oxide, aluminum powder, and slagging agents is reacted in a steel cylinder. Steelmaking-grade ferrocolumbium is also produced from pyrochlore in an electric furnace using essentially the same reactants as in the aluminothermic process. Heat input can be better controlled with the electric furnace process, and columbium recovery is generally better than for the aluminothermic process. The extraction of columbium from other columbium-bearing concentrates involves dissolution with hydrofluoric acid followed by liquid-liquid extraction with methyl isobutyl ketone (MIBK). This procedure efficiently recovers columbium in a form that then can be further processed into columbium oxide. Columbium oxide is aluminothermically reduced batchwise to produce high-purity ferrocolumbium, nickel columbium, and columbium metal. In some cases, the reactions are carried out in water-cooled copper reactors to avoid contamination by refractory materials. Aluminothermically produced columbium metal is commonly purified to remove aluminum and other contaminants by remelting it in an electron-beam furnace. Several remelts may be required before the desired level of purity is reached and a ductile ingot has been produced (Cunningham, 1985; Miller, Fantel, and Buckingham, 1986, p. 8-10; Schlewitz, 1996).

Table 1. U.S. salient columbium scrap statistics, 1998
[Metric tons columbium content, unless otherwise specified]

Old scrap:	
Generated[1]	2,900
Consumed[2]	1,000
Value consumed (million dollars)	20
Recycling efficiency[3] (percent)	50
Supply[4]	3,000
Unrecovered[5]	1,500
New scrap consumed[6]	800
New-to-old scrap ratio[7] (percent)	44:56
Recycling rate[8] (percent)	22
U.S. net exports of scrap[9]	400
Value of U.S. net exports of scrap (million dollars)	6

[1]Columbium content of products theoretically becoming obsolete in the United States in 1998. It excludes dissipative uses.
[2]Columbium content of products that were recycled in 1998.
[3](Old scrap consumed plus old scrap exported) divided by (old scrap generated plus old scrap imports).
[4]Old scrap generated plus old scrap imports.
[5]Old scrap generated plus old scrap imports minus old scrap consumed minus old scrap exports.
[6]Prompt industrial scrap (excluding home scrap).
[7]Ratio of quantities consumed, in percent.
[8]This is the fraction of supply that is scrap on an annual basis. It is defined as old plus new scrap consumed divided by apparent supply [primary plus secondary production (old plus new scrap) plus imports minus exports plus adjustment for Government stock changes], in percent.
[9]Trade in scrap is assumed to be principally in old scrap.

USES

The principal use for columbium is in the form of steelmaking-grade ferrocolumbium. Ferrocolumbium is typically available in grades containing from 60% to 70% columbium. Steelmaking accounts for more than 80% per year of reported columbium consumption in the United States. In 1998, estimated end-uses for columbium in the United States were microalloyed steels, 66%; stainless steels, 14%; superalloys, 19%; and other, which includes superconducting materials, 1%. The end-use patterns for columbium in the remainder of the world were similar to those of the United States with microalloyed steels being the predominant end-use sector (Tantalum-Niobium International Study Center, 1999b). In the 1960's and early 1970's, two significant events increased columbium use—the introduction of columbium as an important microalloying element in steel and the development of nickel-base alloys, which made use of columbium in alloys for jet engine components. U.S. columbium consumption during the past 20 years is shown in figure 2.

Columbium-bearing microalloyed steels are used in oil and gas pipelines, automobiles, buildings, bridges, etc., where the strength-to-weight and cost-per-unit-strength ratios are advantageous. In the automobile industry, the use/amount of high-strength columbium-containing steel has continued to increase despite the trend to reduce the total amount of steel in automobiles. High-strength low-alloy steels allow designers to save weight and to reduce fabrication cost.

Because of its refractory nature, appreciable amounts of columbium in the form of high-purity ferrocolumbium and nickel columbium are used in nickel-, cobalt-, and iron-base superalloys for such applications as jet engine components, rocket subassemblies, and heat-resisting and combustion equipment. Columbium in superalloys strengthens the alloy at high service temperatures, such as in aircraft

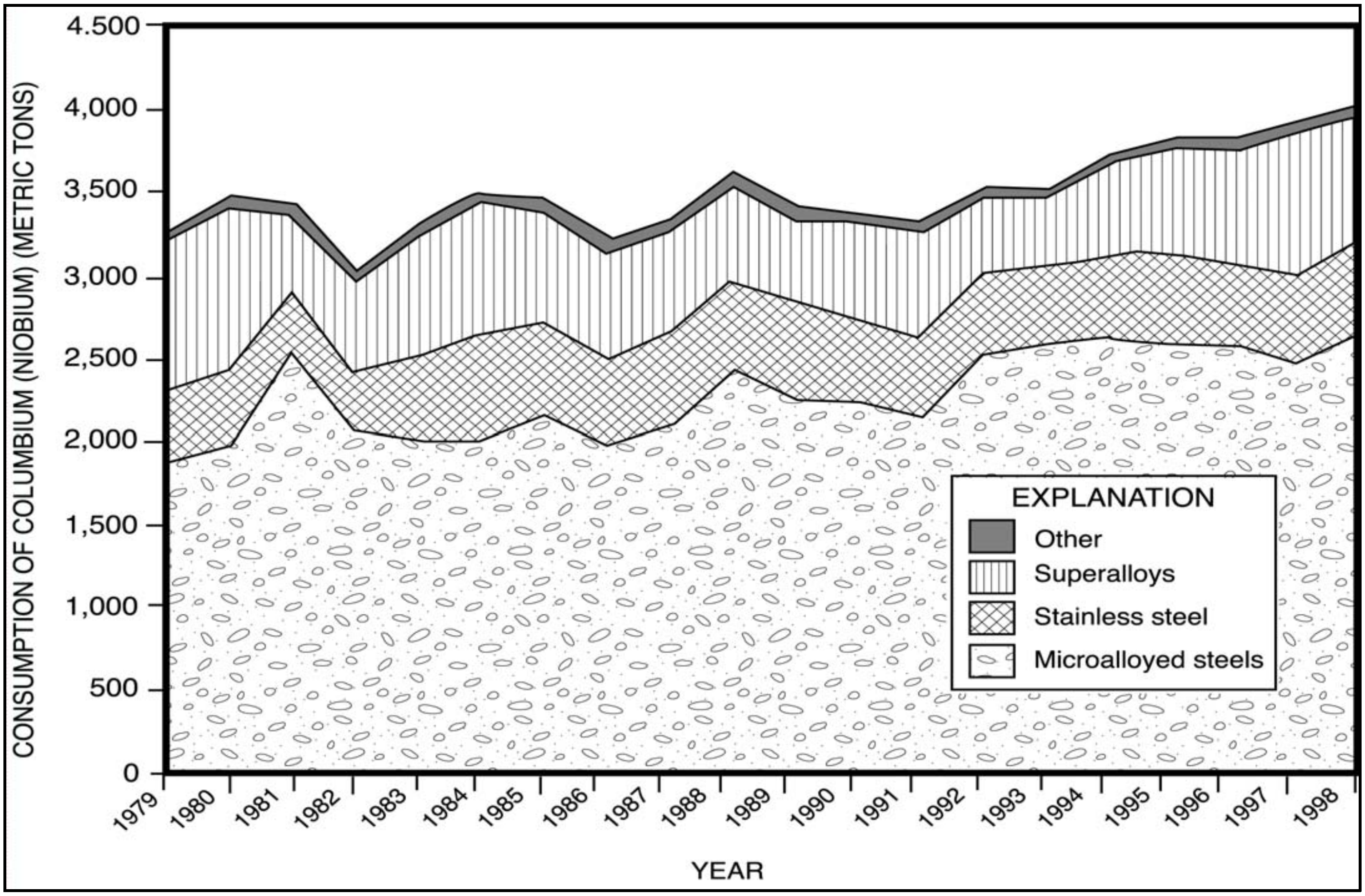

Figure 2. U.S. columbium end-use patterns, 1979-98, in metric tons contained columbium.

engine components. Most columbium-containing superalloys contain up to 2% columbium; some cobalt- and nickel-based superalloys, however, contain up to 6% columbium.

Columbium and some of its alloys exhibit a lack of electrical resistance at very low temperatures (superconductivity) in such applications as in magnetic resonance imaging (MRI) devices for medical diagnostics. Columbium carbide is used in cemented carbides to modify the properties of the cobalt-bonded tungsten carbide-base material to impart toughness and shock resistance. It is usually used along with carbides of other metals, such as tantalum and titanium, in tool bits, drill bits, shovel teeth, and other wear-resistant components; these are small end-use sectors for columbium. Columbium oxide is the intermediate product used in the manufacture of high-purity ferrocolumbium, nickel columbium, columbium metal, and columbium carbide.

PRICES

During the 1990's, the columbium price remained stable owing to the availability of columbium from Brazil and Canada. Brazil's production of columbium concentrates, mostly pyrochlore, accounts for more than 85% of total world columbium production. As the dominant columbium producer/supplier, Brazil has maintained a marketing strategy of stable supply and moderate price changes. Events that had some impact on the columbium price during the 1990's include Canada's startup of steelmaking-grade ferrocolumbium production, initiation of sales of columbium materials from the National Defense Stockpile, and Brazil's expansion of its ferrocolumbium production capacity (Cunningham, 1999). A price for Brazilian pyrochlore has not been available since 1981, and the published price for pyrochlore produced in Canada was discontinued in early 1989.

The price of columbium is affected most by the availability of steelmaking-grade (regular-grade) ferrocolumbium produced from pyrochlore. In 1998, the American Metal Market published price for regular-grade ferrocolumbium ranged from \$6.75 to \$7.00 per pound of contained columbium. The Metal Bulletin price for columbite ore, which is based on a minimum 65% contained columbium oxide (Nb_2O_5) and tantalum oxide (Ta_2O_5), ranged from \$2.80 to \$3.20 per pound. The American Metal Market published price for high-purity (vacuum-grade) ferrocolumbium ranged from $17.50 to $18.00 per pound of contained columbium. Industry sources indicated that nickel columbium sold at about $18.50 per pound of contained columbium, columbium metal products sold in the range of about $24 to $100 per pound in ingot and special shape forms, and columbium oxide for master alloy production sold for about $8.80 per pound (Mining Journal, 1999; Tantalum-Niobium International Study Center, 1999a). In 1998, no price for any type of columbium scrap was published. For this report, the price for columbium contained in steel scrap was taken to be the average published price for steelmaking-grade ferrocolumbium (about $6.90 per pound of contained columbium). The price for columbium contained in superalloy scrap was taken to be the average published price for high-purity ferrocolumbium and nickel columbium (about $18 per pound of contained columbium).

SOURCES OF COLUMBIUM SCRAP

Columbium in the form of steelmaking-grade ferrocolumbium is used as an additive in steelmaking to improve strength and corrosion resistance characteristics in some steels. Less than 10% of steel produced in the world has been estimated to benefit from the advantages of columbium addition (Tantalum-Niobium International Study Center, 1993, p. 4; Roskill Information Services, 1998, p. 110).

In steelmaking, the addition of ferrocolumbium to the steel bath is accompanied by a number of physical and chemical processes. Ferrocolumbium is heated above its melting point, and the columbium dissolves into the liquid metal. After a period of time, by mass transfer processes, the columbium is dissipated throughout the entire volume of the liquid steel in the bath (Lyakishev, Tulin, and Pliner, 1984, p. 199).

Most columbium-containing steels contain less than 0.1% columbium, but some stainless steels can contain as much as 1.25% columbium. A major market for columbium among stainless steels is in type 347, which contains about 0.8% columbium. Stainless steel scrap is almost always used to produce more stainless steel. The scrap is mainly recycled as either home or purchased scrap; demand is usually a function of demand for the stainless steel itself. Columbium mostly in the form of high-purity grade ferrocolumbium and nickel columbium is added to nickel- and cobalt-base superalloys in applications such as jet engine components. The most important columbium-containing superalloy, nickel-base alloy Inconel 718, contains about 5% columbium. Of the total superalloy scrap processed worldwide in 1996, about 70% was recycled into the same alloy; about 20%, downgraded; and the remaining 10%, sold to nickel refineries (ASM International, 1998).

Although columbium is not recovered from the scrap steel and superalloys that contain it, recycling of these scrap materials is significant, and columbium content, where applicable, can be reused. Much of the columbium 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. New columbium-bearing scrap is generated mostly from manufacturing plants that produce steel products and fabricators of parts made from superalloys. This type of scrap is usually quickly returned to steel plants and superalloy meltors for remelting. Some major sources for old columbium-bearing scrap are junked automobiles (estimated 10-year lifetime) and scrap from discarded or obsolete parts made from superalloys (estimated 20-year lifetime), such as jet engine components. In 1998, columbium scrap sources consisted of steel scrap (estimated at about 70% of the total) and superalloy scrap (estimated at about 30% of the total). A major end use for columbium has been in columbium-bearing high-strength low-alloy steels for oil and gas pipelines (estimated 60-year lifetime). These steels were introduced during the 1970's and will be a potential significant future source of columbium-bearing steel scrap.

DISPOSITION OF COLUMBIUM SCRAP

In 1998, the quantity of columbium recycled/reused from old scrap represented about 12% of domestic columbium supply. With no U.S. columbium mining industry, columbium-bearing old scrap is important to the columbium supply chain. Of the estimated 3,000 t of columbium contained in old scrap that was available for recycling in 1998, about 33% was used for domestic columbium supply, and about 50% was unrecovered. Most of the unrecovered material was in the form of steel scrap that was lost to the environment, shipped to landfills, or abandoned in place. Scrap that was abandoned or in landfills could possibly be recycled in the future.

RECYCLING EFFICIENCY

Recycling efficiency shows the relation between what is theoretically available for recycling and what was recovered and not recovered. By definition, this relation was the amount of old scrap consumed plus exports divided by the sum of old scrap generated and scrap imports plus or minus scrap stock changes, as applicable. Most columbium is recycled/reused in the form of columbium-bearing steel and superalloy scrap. A columbium recycling efficiency of about 50% was estimated to have been reached in 1998 compared with 52% for steel.

INFRASTRUCTURE

No columbium was mined in the United States in 1998; metal, ferrocolumbium, other alloys, and compounds, however, were produced mostly by six companies. Cabot Performance Materials, Boyertown, PA, had a production capability that ranged from raw material processing through to the production of columbium end products. Shieldalloy Metallurgical Corp., Newfield, NJ, was a producer of ferrocolumbium. H.C. Starck Inc., Newton, MA, was a supplier of columbium products. Reading Alloys, Inc., Robesonia, PA, and Oremet-Wah Chang, Albany, OR, were major producers of high-purity columbium products. Kennametal, Inc., Latrobe, PA, was a supplier of columbium carbides. Columbium consumption was mainly in the form of steelmaking-grade ferrocolumbium by the steel industry and high-purity columbium alloys and metal by aerospace-related industries with plants in the Eastern United States, the Midwestern United States, California, and Washington.

Columbium recycling mainly occurs in the iron and steel and alloys-related industries. A companion report on Steel Recycling in this series discusses the infrastructure for the recycling of steel scrap (Fenton, in press). The largest concentration of recycling facilities is in the heavily populated northern and eastern regions of the country where steel product use and scrap generation are greatest.

The superalloy recycling industry comprises mainly superalloy processors, scrap generators, scrap dealers, and scrap consumers. Scrap is generated when superalloys are produced, cast, or wrought into semifinished products, cut or ground into finished products, and when finished products become obsolete. The scrap is collected, sorted, cleaned, sized, and certified for chemical composition by a superalloy scrap processor before it reenters the superalloy-use cycle. The numerous material flow relations among superalloy scrap generators, collectors, dealers, processors, and brokers obscure the quantity of superalloy scrap that is available for recycling, the quantity that is downgraded, and the quantity that is imported or exported. Superalloy scrap recycling facilities are located mostly in the eastern, mid-eastern, and western regions of the country wherein lies the larger concentration of superalloy producers and end users (Papp, 1988).

Trade in columbium scrap is relatively small, and data are not available. The U.S. International Trade Commission’s Harmonized Tariff Schedule System categorizes some selected columbium materials. The system, however, categorizes columbium waste and scrap in a nonspecific tariff classification, and, in 1998, no trade figures for import or export of columbium scrap were identified. However, the columbium content of columbium-bearing steel and superalloy scrap imports and exports was estimated to be about 100 t and 500 t, respectively, in 1998.

The United States imports most of its columbium requirements. In 1998, U.S. imports of ferrocolumbium and columbium alloys, metal, and powders totaled about 5,450 t of contained columbium and were valued at about $83 million. Imports came mostly from Brazil and Canada. Columbium exports, mainly ferrocolumbium, totaled about 20 t of contained columbium valued at more than $200,000. Germany and Mexico were the major recipients of the materials.

PROCESSING OF COLUMBIUM-BEARING SCRAP

IRON AND STEEL SCRAP

Scrap is collected by scrap dealers and processed into a physical form and chemical composition that can be consumed by steel mills in their furnaces. The shredder, which is the largest and most expensive piece of equipment used in recycling, fragments vehicles and other discarded steel into fist-sized pieces. Baling presses are used to compact the scrap into manageable-size bundles. Scrap dealers sort scrap materials, and steelmakers carefully purchase scrap that does not contain undesirable elements that exceed acceptable levels. The scrap is mainly melted in basic oxygen and electric arc furnaces. In the fabrication of new steel products, new steel scrap with known chemical composition is produced. Preparation of the new scrap for recycling is usually limited to cutting, cleaning, and baling prior to shipment back to the steelmaker. The processing of iron and steel scrap is discussed in the Steel Recycling report in this series (Fenton, in press). Stainless steel is recycled in a similar manner as iron and steel scrap, but the volume of material is less, and the value is greater. Increased demand raises the value of scrap, which enables more scrap to be recycled. Scrap dealers compete for stainless steel on national and international bases, and the scrap may be handled at several locations before it is sold for use (ASM International, 1998). Scrap separated by alloy type usually brings the highest price. Balers are used to compress the scrap, and shredders are rarely used.

SUPERALLOYS

The processing of superalloy scrap can be difficult and complicated. There are hundreds of superalloys that contain more than 20 alloying elements, and each element must be considered when designing and evaluating processes for separating and recovering the valuable metals. Each piece of superalloy scrap must be identified and its composition certified before it is sold. Turnings are degreased, fragmented, and compressed for remelting. Balers are used to compress superalloy scrap; shredders are rarely used.

Superalloys are usually air melted or vacuum melted. Recycled scrap is acceptable for most air-melted alloys. Product specifications, however, usually prohibit the use of recycled scrap in vacuum-melted alloys to reduce the chance that detrimental impurities may be included in the final product, such as in critical components for jet engines. Owing to the high cost and/or periodic scarcity of superalloys, scrap recycling is used extensively (Gupta and Suri, 1994, p. 139-140; ASM International, 1998).

Scrap is a preferred furnace charge for superalloy melters and can provide about 50% of a superalloy furnace charge. Scrap is prerefined, prealloyed, and easy to handle. New or home scrap turnings are the largest form of superalloy scrap. Vacuum-quality turnings are collected to produce a furnace-ready charge that can be easily melted. The first step is a qualitative verification of chemical purity to isolate severely contaminated material from chemically clean material. Turnings are crushed into chips, which are then cleaned of residual cutting fluids and dirt. Lot homogenization and certification follows; processed scrap is required to meet the same chemical requirements as the finished heat. In the case of alloy Inconel 718, which has a lower melting point than its constituents, using processed scrap in the melt saves on electrical costs and melting time (Lane, 1998). This scrap is then either remelted in the plant where it was originally produced (home scrap) or sold for remelting at another plant (new scrap).

OUTLOOK

A 20-year pattern of columbium consumption is shown in figure 2. The principal use for columbium is expected to continue as an additive in steelmaking, mostly in the manufacture of microalloyed steels used for pipelines, bridges, automobiles, and so forth. The production of high-strength low-alloy steel is the leading use for columbium, and the trend of columbium demand, domestically and globally, will continue to follow closely that of steel production. With about 80% of columbium being consumed in steelmaking, columbium recycling trends will be determined most by trends in the recycling of steel, which is discussed in the Steel Recycling report in this series (Fenton, in press). U.S. scrap supply is said to be a function of market price, which affects the collection of obsolete scrap; levels of activity in the metalworking industry, which influences the generation of prompt industrial scrap; and melting activity, which impacts the availability of home scrap (American Metal Market, 2001).

The outlook for columbium also will be dependent on the performance of the aerospace industry and its use of columbium-bearing alloys. Columbium consumption in the production of superalloys, which is the second largest end use for columbium, will be most dependent on the market for aircraft engines. Because nickel-base superalloys (such as alloy Inconel 718, which contains around 5% columbium) can account for about 40% to 50% of engine weight, they are expected to be the materials of choice for the future owing to their high temperature operating capability (Tantalum-Niobium International Study Center, 1999b). Thus, the rate at which columbium is recycled will also depend upon the rate at which products that contain columbium-bearing superalloys are recycled.

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APPENDIX—DEFINITIONS

apparent consumption (AC). Primary plus secondary production (old scrap) plus imports minus exports plus adjustments for Government and industry stock changes.

apparent supply (AS). AC plus consumption of new scrap (CNS).

dissipative use. A use in which the metal is dispersed or scattered, such as paints or fertilizer, making it exceptionally difficult and costly to recycle.

home scrap. Scrap generated as process scrap and consumed in the same plant where generated.

new scrap. Scrap produced during the manufacture of metals and articles for both intermediate and ultimate consumption; it includes all defective finished or semifinished articles that must be reworked. Examples of new scrap are borings, castings, clippings, drosses, skims, and turnings. This includes scrap generated at facilities consuming old scrap. Included as new scrap is prompt industrial scrap obtained from a facility separate from the recycling refiner, smelter, or processor. Excluded from new scrap is home scrap that is generated as process scrap and used in the same plant.

new-to-old-scrap ratio. New scrap consumption compared with old scrap consumption measured in weight and expressed as a percentage of new plus old scrap consumed; for example 40:60.

old scrap. Scrap that includes, but is not limited to, metal articles that have been discarded after serving a useful purpose. Typical examples of old scrap are electrical wiring, lead-acid batteries, metals from shredded cars and appliances, silver from photographic materials, spent catalysts, tool bits, and used aluminum beverage cans. This is also referred to as “postconsumer scrap” and may originate from industry or the general public. Expended or obsolete material used dissipatively, such as paints and fertilizer, are not included.

old scrap generated. Metal content of products theoretically becoming obsolete in the United States in the year of consideration; this excludes dissipative uses.

old scrap recycling efficiency. Amount of old scrap recovered and reused relative to the amount available to be recovered and reused. Defined as [consumption of old scrap (COS) plus exports of old scrap (OSE)] divided by [old scrap generated (OSG) plus imports of old scrap (OSI), plus a decrease in old scrap stocks (OSS) or minus an increase in old scrap stocks], measured in weight and expressed as a percentage; that is,

$$\frac{\text{COS + OSE}}{\text{OSG + OSI + decrease in OSS or - increase in OSS}} \times 100.$$

old scrap supply. Old scrap generated plus old scrap imports plus old scrap stock decrease; that is,

$$\text{OSG + OSI + OSS decrease.}$$

old scrap unrecovered. Old scrap supply minus old scrap consumed minus old scrap exports minus old scrap stock increase; that is,

$$\text{OSS - COS - OSE - OSS increase.}$$

price. Unit value of contained columbium in materials used in calculating total value of contained metal in scrap.

recycling. Reclamation of a metal in useable form from scrap or waste. This includes recovery as the refined metal or as alloys, mixtures, or compounds that are useful. Examples of reclamation are recovery of alloying (or base metals) in steel; recovery of antimony in battery lead; recovery of copper in copper sulfate; and even the recovery of a metal where it is not desired, but can be tolerated—such as tin from tinplate scrap that is incorporated in small quantities (and accepted) in some steels, only because the cost of removing it from tinplate scrap is too high and/or tin stripping plants are too few. In all cases, what is consumed is the recoverable metal content of scrap.

recycling rate. Fraction of the metal apparent supply that is scrap, on an annual basis. It is defined as consumption of old scrap plus consumption of new scrap divided by apparent supply measured in weight and expressed as a percentage; that is,

$$[(COS + CNS)/AS] \times 100.$$

scrap consumption. Scrap added to the production flow of a metal or metal product.