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ZIRCONIUM AND HAFNIUM [ADVANCE RELEASE]

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Zirconium and Hafnium

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In 2015, production of zirconium ore and concentrates in the United States increased and estimated production of milled zircon increased by 6% from that of 2014. U.S. net imports of zirconium ore and concentrates decreased by about 37% (table 1). World production of zirconium mineral concentrates in 2015, which included U.S. production, was about 1.52 million metric tons (Mt), a 6% decrease from the revised 2014 production total, which excluded U.S. production (table 5).

The primary source of zirconium was the mineral zircon ($ZrSiO_4$), principally found in heavy-mineral sands. A relatively small quantity of zirconium was derived from the mineral baddeleyite, a rare natural form of zirconia [zirconium oxide (ZrO_2)] recovered from a single source in Kovdor, Russia. In 2015, the leading producers of zircon were Australia and South Africa. Zircon was also the primary source of hafnium; zirconium and hafnium are contained in zircon at a ratio of about 50 to 1. Zirconium and hafnium metal was produced in China, France, India, Russia, and the United States.

Production

Zircon is a coproduct of the mining and processing of heavy-mineral sands for the titanium minerals ilmenite and rutile. In 2015, the U.S. producers of zircon were The Chemours Co., Iluka Resources, Inc. (a wholly owned subsidiary of Iluka Resources Ltd., Perth, Western Australia, Australia), and Southern Ionics Inc. Chemours produced zircon from its operation near Starke, FL; Iluka produced zircon from its operations near Stony Creek, VA; and Southern Ionics produced zircon from its operation in Nahunta, GA. In December, Iluka terminated its Virginia operations owing to low market prices, weak demand, and exhaustion of reserves. It continued to hold mineral leases of resources located near Aurelian Springs, NC, and Hickory, VA (Iluka Resources Ltd., 2014; 2016a, p. 5).

Twin Pines Minerals LLC was developing a project to produce ilmenite and zircon by reprocessing tailings from former sand operations in New Jersey. A mineral-sands-wet-concentration plant was being constructed with a capacity of 232 metric tons per hour, with production expected to begin in the second quarter of 2016 (Mineral Sands Report, 2014, p. 5; Sedgman Ltd., 2015).

The three domestic producers of zirconium ore and concentrates responded to a U.S. Geological Survey (USGS) voluntary survey of domestic mining operations. Data on domestic production and consumption of zirconium ore and concentrates were rounded to one significant digit to avoid disclosing company proprietary data.

U.S. producers of zirconium and hafnium metal were ATI Wah Chang (an Allegheny Technologies, Inc. business unit) in Albany, OR, and Western Zirconium Inc. (a subsidiary of Westinghouse Electric Co.) in Ogden, UT.

Data for zirconium and hafnium manufactured materials were collected from a voluntary survey of domestic operations. Of the 30 operations surveyed, 8 responded, representing about 90% of estimated domestic production of milled zircon of 46,000 metric tons (t) in 2015. Data for nonrespondents were estimated on the basis of prior-year levels (table 1).

Consumption

Globally, the leading end uses for zircon were ceramics, zirconia, zirconium-based chemicals, refractories, and foundry and casting applications. Zircon sand is preferred in casting applications where high-quality finishes and tight tolerances are required owing to its lower expansion coefficient and greater stability at high temperatures compared with other materials. Zircon recovered from hard-rock mining was valued as a natural gemstone and zirconia powder was processed to produce cubic zirconia, a synthetic gemstone and diamond simulant.

Zirconium metal was used in corrosive environments, nuclear fuel cladding, and various specialty alloys. The principal uses of hafnium were in high-temperature ceramics, nickel-base superalloys, nozzles for plasma arc metal cutting, and nuclear control rods.

Zirconia exhibits high light reflectivity and good thermal stability and was primarily used as an opacifier and pigment in glazes and colors used for pottery and other ceramic products. Yttria-stabilized zirconia (YSZ) was used in the manufacture of oxygen sensors that control combustion in automobile engines and furnaces. YSZ was also used in the manufacture of a diverse array of products, including cubic zirconia, fiber-optic connector components, refractory coatings, and engineering and structural ceramics. YSZ was used in biomedical applications, such as dental bridges, crowns, and inlays, because it has two to three times the fracture resistance and 1.4 times the strength of alternative alumina products.

Zircon, used for facings on foundry molds, increases resistance to metal penetration and gives a uniform finish to castings. Milled or ground zircon was used in refractory paints for coating the surfaces of molds. Refractory bricks and blocks containing zircon were used in furnaces and hearths for containing molten metals. Fused-cast and bonded alumina-zirconia-silica-base refractories were used in glass-tank furnaces.

Baddeleyite was used principally in the manufacture of alumina-zirconia abrasives and in ceramic colors and refractories. Ammonium- and potassium-zirconium carbonates were used as paper and board coatings or insolubilizers for high-quality print performance. Zirconium chemicals were also used in inks to promote adhesion to metals and plastics, and as crosslinkers in polymers and printing inks.

Because of its low thermal neutron absorption cross section, hafnium-free zirconium metal was used as cladding for nuclear

fuel rod tubes. Hafnium was used in nuclear control rods because of its high thermal neutron absorption cross section. Commercial-grade zirconium, unlike nuclear grade, contains hafnium and was used in chemical process industries because of its excellent corrosion resistance. Hafnium metal also was used as an additive in superalloys.

Prices

The 2015 yearend published price range of standard-grade bulk domestic zircon concentrate was $950 to $1,100, almost unchanged from yearend prices of 2014. The published yearend price range of refractory/abrasive zirconia was $6,000 to $7,000, almost unchanged from the previous year (table 2). According to U.S. Census Bureau data, the average unit value of imported zirconium ore and concentrates in 2015 was $1,166 per ton, a 3% decrease from that of 2014 (table 4).

No published prices were available for zirconium or hafnium metal. In 2015, the average duty-paid unit value of imported unwrought zirconium (including sponge and powder) from China, the leading source of U.S. zirconium imports, decreased by 72% from that in 2014 to $17 per kilogram. The decrease was reportedly owing to global overcapacity and inventory liquidation by producers in order to regain revenue (Metal-Pages, 2016). The average duty-paid unit value of zirconium from France, a major producer of nuclear-grade zirconium, which accounted for 1% of imports, was $49 per kilogram, a decrease of 15% from that in 2014. The average duty-paid unit value of imported unwrought hafnium (including sponge and powder) from France was $607 per kilogram, an 8% increase from that in 2014 (table 4).

Foreign Trade

In 2015, exports of zirconium ore and concentrates continued the downward trend and decreased by 30% to 6,270 t (table 1). Although imports decreased from 50,400 t to 31,900 t (37%), since 2014 the United States imported larger quantities and exported smaller quantities of zirconium ores and concentrates, likely owing to the ending of U.S. operations in Virginia by Iluka and continued low zircon prices. South Africa, Senegal, and Australia supplied most of the zirconium ores and concentrates (56%, 24%, and 14%, respectively) imported into the United States (table 4).

Most zirconium metal, excluding ferrozirconium, was exported in wrought products classified as "Other zirconium" in the Harmonized Tariff Schedule of the United States (HTS) code 8109.90.0000 (table 3). Exports of zirconium metal totaled 1,020 t in 2015, an 8% increase from revised totals of 2014 (table 3). Imports of zirconium metal were 171 t, a 33% decrease from 2014 (table 4).

Imports of hafnium metal, HTS code 8112.92.2000, totaled 72 t, more than three times imports in 2014 (table 4). Imports of germanium and zirconium oxides, HTS code 2825.60, decreased by 2% to 4,204 t in 2015; China (49%) and France (33%) were the leading import sources of oxides. Imports of ferrozirconium alloys increased to 158 t in 2015, an increase of 20% from those of 2014.

World Review

World production of zirconium mineral concentrates in 2015, which included U.S. production, was about 1.52 Mt, a 6% decrease compared with revised 2014 production data. The major global zircon producers were Iluka Resources Ltd., Rio Tinto plc (Melbourne, Victoria, Australia), and Tronox Ltd. (Stamford, CT). Australia and South Africa supplied about 66% of all production outside the United States.

Australia.—Iluka Resources produced 351,000 t of zircon from its operations in Australia, an increase of 6% compared with that of 2014. Production was 297,000 t from its operations in the Eucla Basin, South Australia, and the Perth Basin, Western Australia, and 54,000 t from its operations in the Murray Basin, Victoria (Iluka Resources Ltd., 2016a, p. 5, 22).

MZI Resources Ltd. completed construction of its Keysbrook project and began mining heavy-mineral concentrates in October. By yearend, Keysbrook had produced 1,775 t of zircon and had shipped 1,000 t to China (MZI Resources Ltd., 2016, p. 3).

In New South Wales, Alkane Resources Ltd. continued to develop its Dubbo Zirconia project and planned to produce hafnium, niobium, rare-earth, tantalum, and zirconium products. Based on recoveries developed from the demonstration pilot plant, 25,200 metric tons per year (t/yr) of combined output was expected, including zirconium carbonate (equivalent to 16,300 t/yr of ZrO_2) and more than 200 t/yr of hafnium oxide. Ore reserves were sufficient to support a 35-year mine life. Alkane received State and Federal environmental approvals in 2015 and was expecting to begin construction in 2016 with production to begin in 2018 (Alkane Resources Ltd., 2015, p. 4, 5, 10, 17).

China.—China imported 1.05 Mt of zircon concentrates in 2015, an increase of 30% from that of 2014, but the average value decreased by 10% to $752 per metric ton (Mineral Sands Report, 2016, p. 29).

By the end of 2015, major zirconium metal producers were reportedly operating at reduced capacity due to overcapacity issues. Other producers had stopped producing zirconium sponge and were liquidating existing stock (Metal-Pages, 2016).

The Shanghai Hafeng New Materials Science and Technology Co., Ltd. applied for a national patent based on a new zirconium and hafnium separation technology. Shanghai Hafeng also announced the planned construction of a new operation, with an annual capacity of 200,000 t/yr of zirconium and 3,000 t/yr of hafnium, to be built in Jiangsu. No timetable was given for start of construction (Beijing Ruidow Information Technology Co. Ltd., 2015).

Kenya.—Base Resources Ltd. reported that it produced 26,000 t of zircon from its Kwale operation in 2015, the first full year of production. The production target for 2016 was 27,000 to 30,000 t of zircon (Base Resources Ltd., 2016, p. 1, 4).

Mozambique.—Kenmare Resources plc produced 51,800 t of zircon at its Moma Mine in 2015, an increase of 2% from that of 2014 (Kenmare Resources plc, 2016, p. 1).

Senegal.—Mineral Deposits Ltd. reported that it produced 45,200 t of zircon at its Grande Côte project in 2015, the first

full year of production. The company planned to increase zircon production in 2016. At full production levels, Mineral Deposits expected to produce 85,000 t/yr of zircon over a 25-year mine life (Mineral Deposits Ltd., 2014; 2016, p. 19).

South Africa.—Tronox Ltd. expected to begin operations at its Fairbreeze Mine in 2016. During a 12-year mine life, the Fairbreeze Mine was expected to produce 60,000 t/yr of zircon (Tronox Ltd., 2015, p. 25).

Mineral Commodities Ltd. reported that it produced 44,489 t of zircon-rutile concentrate, grading 72.88% zircon and 13.44% rutile, at their Tormin Mine in 2015, an increase of 4% from that of 2014 (Mineral Commodities Ltd., 2016, p. 5).

Outlook

As a major producer, Iluka expected the zircon market would continue to remain oversupplied and that production would decrease in 2016 (Iluka Resources Ltd., 2016a, p. 15; 2016b, p. 22, 24). TZ Minerals International Pty Ltd., a major industry analyst of the zircon and titanium mineral sands industry, expected global zircon demand to increase by 3% to 4% per year from 2015 to 2020 (Metal-Pages, 2015).

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TABLE 1
SALIENT U.S. ZIRCONIUM STATISTICS[1]

(Metric tons, gross weight)

	2011	2012	2013	2014	2015
Zirconium ore and concentrates:					
Production:					
Concentrates	W	W	W	W	80,000 [2]
Milled zircon[e]	53,600	48,200	48,200	43,300	46,000
Exports	24,300	20,000	29,200	9,020 [r]	6,270
Imports for consumption[3]	26,500	25,800	12,400	50,400	31,900
Consumption, apparent[4]	W	W	W	W	100,000 [2]
Zirconium oxide:					
Exports[5]	6,700	6,230	7,000	7,380	5,740
Imports for consumption[5]	3,010	4,550	3,170	4,240	4,200
Zirconium, unwrought, waste and scrap, other:					
Exports	2,000	1,800	1,740	1,480 [r]	1,540
Imports	875	567	714	1,100	1,320
Ferrozirconium alloys:					
Exports	2,680	2,560	1,980	1,710 [r]	1,620
Imports	88	6	4	131	158
Hafnium, unwrought, waste and scrap, other, imports	10	24	10	21	72

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Data are rounded to no more than three significant digits.
[2]Data are rounded to no more than one significant digit to avoid disclosing company proprietary data.
[3]Includes insignificant amounts of baddeleyite.
[4]Defined as production plus imports for consumption minus exports plus or minus Government shipments.
[5]Includes germanium oxides and zirconium dioxides.

TABLE 2
PUBLISHED YEAREND PRICES OF ZIRCONIUM MATERIALS

(Dollars per metric ton)

Material	2014	2015
Zircon:		
Domestic, standard-grade, bulk	950–1,150	950–1,100
Australian, standard-grade, free on board, bulk	1,000–1,050	1,000–1,050
Zirconia, fused, monoclinic, refractory/abrasive	6,000–6,900	6,000–7,000

Source: Industrial Minerals.

TABLE 3
U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY[1]

Class and country	HTS[2] code	2014 Quantity (metric tons)	2014 Value (thousands)	2015 Quantity (metric tons)	2015 Value (thousands)
Zirconium ore and concentrates:	2615.10.0000				
Argentina		34	$114	89	$122
Belgium		690	1,850	728	1,840
Brazil		13	55	314	920
Canada		1,510	4,440	1,390	4,110
Chile		143	234	179	253
China		295	733	314	688
Dominican Republic		24	39	24	38
France		658	1,920	631	1,860
Germany		97	287	87	254
India		68	206	152	418
Israel		62	177	71	221
Italy		248	491	96	269
Japan		381	1,160	327	1,010
Korea, Republic of		144	383	19	53
Mexico		3,360	6,720	1,030	2,790
Ukraine		196	272	24	34
United Kingdom		667	2,310	629	2,100
Other		427 r	770 r	164	398
Total		9,020 r	22,200 r	6,270	17,400
Ferrozirconium alloys:	7202.99.1000				
Mexico		1,680 r	4,040 r	1,580	3,180
Other		25	71	33	90
Total		1,710 r	4,110 r	1,620	3,270
Unwrought zirconium, including powder:	8109.20.0000				
Canada		7	309	16	535
France		2	125	3	122
Russia		16	1,090	10	660
Sweden		114	6,230	49	2,590
United Kingdom		138	2,700	76	1,350
Other		48 r	1,840 r	60	2,100
Total		325	12,300 r	214	7,350
Zirconium waste and scrap:	8109.30.0000				
Belgium		65	905	110	1,190
Canada		43	2,490	92	4,460
Italy		7	159	9	174
Japan		7	137	7	176
United Kingdom		86	843 r	82	876
Other		--	--	5	112
Total		209	4,540 r	305	7,000
Other zirconium:	8109.90.0000				
Argentina		16	1,640	38	3,790
Canada		358 r	32,700 r	352	37,900
China		58	6,090	103	10,300
France		74 r	4,580 r	18	2,560
Germany		24	1,150	30	1,300
Japan		49	4,650	89	6,360
Korea, Republic of		255	33,000	165	21,500
Spain		14	731	2	277
Sweden		53	7,570	111	14,500
Taiwan		7	480	41	3,190
United Arab Emirates		--	--	31	3,480
United Kingdom		4	442	7	734
Other		30 r	3,050 r	31	3,760
Total		944 r	96,000 r	1,020	109,000

rRevised. -- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Harmonized Tariff Schedule of the United States.

Source: U.S. Census Bureau.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF ZIRCONIUM AND HAFNIUM, BY CLASS AND COUNTRY[1]

Class and country	HTS[2] code	2014 Quantity (metric tons)	2014 Value (thousands)	2015 Quantity (metric tons)	2015 Value (thousands)
Zirconium ore and concentrates:	2615.10.0000				
Australia		18,200	$22,300	4,610	$5,710
China		233 r	929 r	318	846
Russia		860	3,880	680	2,910
Senegal		40	44	7,690	9,490
South Africa		30,400	32,700	17,800	16,700
Other		696 r	956 r	809	1,500
Total		50,400	60,800	31,900	37,200
Ferrozirconium alloys:	7202.99.1000				
Argentina		--	--	20	45
Canada		40	307	23	81
China		91	467	114	540
United Kingdom		--	--	1	2
Total		131	774	158	668
Unwrought zirconium, including powder:	8109.20.0000				
Belgium		3	57	--	--
Canada		18	204	(3)	29
China		381	20,900	787	11,800
France		11	624 r	11	528
Germany		74	3,940	92	4,460
Japan		86 r	770 r	65	563
Other		(3)	4 r	(3)	25
Total		572 r	26,500	954	17,400
Zirconium waste and scrap:	8109.30.0000				
Australia		175	243	97	121
Canada		3	62	31	62
France		28	312	7	81
Germany		10	220	0	2
Japan		26	130	19	90
Korea, Republic of		11	237	13	210
Other		18	213	23	237
Total		271	1,420	190	804
Other zirconium:	8109.90.0000				
Canada		21	2,050	16	2,050
France		197	43,200	100	16,900
Germany		15	3,460	27	5,290
Other		24 r	2,010 r	28	2,660
Total		257	50,700	171	26,900
Unwrought hafnium, including powder:	8112.92.2000				
France		11	6,160	15	8,920
Germany		8	3,900	32	7,130
Other		2	768	25	3,340
Total		21	10,800	72	19,400

rRevised. -- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Harmonized Tariff Schedule of the United States.
[3]Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 5
ZIRCONIUM MINERAL CONCENTRATES: WORLD PRODUCTION, BY COUNTRY [1, 2]

(Metric tons, gross weight)

Country[3]	2011	2012	2013	2014	2015[e]
Australia	762,000	605,000	388,000	798,000 [r]	567,000
Brazil	23,283	20,425	21,154 [r]	21,000 [r]	21,000
China[e]	150,000	140,000	150,000	150,000	140,000
India	39,000	40,000	40,000	40,000	40,000
Indonesia[e]	130,000	120,000	120,000	110,000	110,000
Kenya	--	--	--	15,004	25,950 [4]
Madagascar	18,242 [r]	31,242 [r]	31,345 [r]	18,000 [r, e]	18,000
Malaysia	1,685	442	379	380 [r, e]	400
Mozambique	43,600	46,900	31,400	50,800 [e]	51,800 [4]
Russia[5]	8,914	7,969	8,504 [r]	8,500 [r, e]	8,000
Senegal	--	--	--	9,040	45,248 [4]
Sierra Leone	8,496	1,120	2,951 [p]	2,357	1,400 [4]
South Africa	432,282 [r]	367,190 [r]	224,446 [r]	360,156 [r]	380,000
Sri Lanka[e]	641 [r]	292 [r]	227 [r]	600 [r]	1,564 [4]
Ukraine[e]	26,000	20,000	41,000	27,000 [r]	30,000
United States	W	W	W	W	80,000 [6]
Vietnam[7]	14,000 [r]	15,600 [r]	7,600 [r]	8,500 [r]	3,400
Total	1,660,000 [r]	1,420,000 [r]	1,070,000 [r]	1,620,000 [r]	1,520,000

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total." -- Zero.

[1]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes data available through July 27, 2016.

[3]In addition to the countries listed, small amounts of zirconium mineral concentrates were produced in various countries, but available information is not sufficient to make reliable estimates of output.

[4]Reported figure.

[5]Production of baddeleyite concentrate averaging 98% ZrO_2.

[6]Rounded to one significant digit to avoid disclosing company proprietary data.

[7]Estimated figures based on Vietnam inferred exports of zirconium ore to China.