MINERAL SANDS PRODUCTS: ATTRIBUTES AND APPLICATIONS

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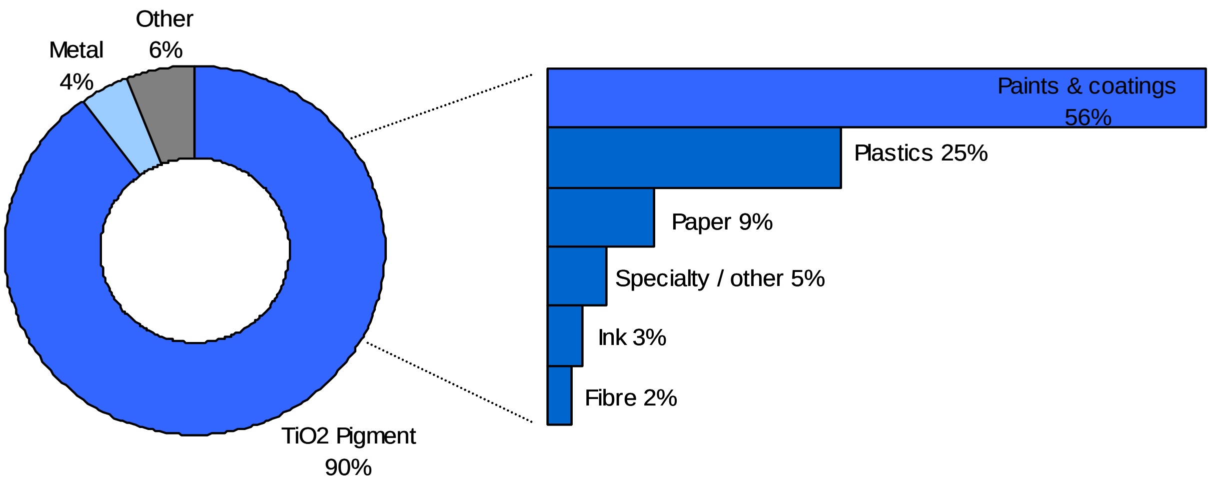
Mineral sands refers to heavy minerals (HM) with a specific gravity greater than 2.85, and consists of two core product streams: titanium dioxide (TiO_2) in the form of rutile, ilmenite and leucoxene, and zircon. Ilmenite is used in its natural form and also to manufacture titanium slag and synthetic rutile products.

Titanium dioxide and zircon products have physical and chemical properties which make their application important to a wide range of end use applications. While some partial substitutes exist, none have the inherent attributes of, for example, titanium dioxide's utilisation in pigment production or zircon's attributes in the manufacture of a range of ceramic applications.

TITANIUM DIOXIDE

The titanium dioxide products of ilmenite, rutile, leucoxene, as well as upgraded products of synthetic rutile and titanium slag, are used principally as feedstocks for the production of white pigment. This application accounts for over 90 per cent of global titanium dioxide feedstock consumption. The remainder is used for the production of titanium sponge, used in the manufacture of titanium metal, as well as in welding as an electrode flux.

2010 TiO_2 Feedstock Demand by Industry Sector



Total 2010 TiO_2 consumption ~6,300kt

Source: TZMI

The value in use of naturally occurring titanium and upgraded ilmenite products is in large measure influenced by their respective titanium dioxide content, shown in the table below.

TiO_2 Content of Titanium Dioxide Products

Form of Titanium	% TiO_2 Content
Rutile	92 - 96
Leucoxene	65 - >90
Titanium Slag / Synthetic Rutile	88 - 94
Ilmenite	48 - 55

Titanium Dioxide Pigment

Titanium dioxide has a high refractive index (refer to the table below), which means that it is able to scatter and bend light strongly. When enough titanium dioxide pigment is used in a medium almost all visible light will be reflected, giving the appearance of it being opaque, white and bright. Opacifiers are most effective when their refractive index differs from the medium in which it is suspended. In this regard, titanium dioxide has a significant advantage over other commercially available pigments.

This quality is utilised extensively in the manufacture of paints and coatings, plastics, paper and in a range of other applications, including inks, fibres, rubber, food, cosmetics and pharmaceuticals. Plastics is the fastest growing sector, with its major application in the packaging industry.

Refractive Index of Some White Pigments

Pigment	Refractive Index
Rutile TiO_2	2.70
Anatase TiO_2	2.55
Zinc Sulphide	2.37
Antimony Oxide	2.30
Lithopone 30%	1.84
Zinc Oxide	2.02
White Lead	2.00
China Clay	1.57

Source: Huntsman Tioxide, Manufacturing and General Properties of Titanium Dioxide Pigments

Titanium dioxide has the ability to asborb ultraviolet (UV) light, efficiently transforming destructive UV light energy into heat. When added to materials such as paints and plastics, it prevents UV degradation including fading, peeling and cracking. Titanium dioxide is also used as a component in the manufacture of sunscreens, cosmetics and skin care products designed to protect human skin from UV damage.

Rutile and synthetic rutile, utilised in the pigment industry, have a relatively high titanium dioxide content (greater than 88 per cent), and contain low levels of contaminants that can affect the chlorination process which is used in pigment production.

Titanium dioxide pigment is non-toxic and biologically inert, making it safe for use in a range of consumer applications such as in foods, cosmetics and pharmaceuticals.

There is no economic or environmentally safe alternative to titanium dioxide in pigment. Titanium dioxide replaced lead in consumer end use applications, such as paint, due to public health issues related to lead toxicity.

Titanium Metal

High grade titanium dioxide products are the principal feed source for the manufacture of titanium metal. Titanium is an important strategic material, used in commercial aerospace (the fastest growing segment) and in military and industrial applications, as well as in a range of commercial, infrastructure and consumer applications.

Significant governmental and commercial R&D work is being undertaken to attempt to determine a commercially applicable means of cost-effectively transforming titanium dioxide directly into titanium metal, as opposed to the current batch production process. If this were to occur, titanium metal would be expected to substitute for high quality steel (stainless steel) in many applications, given its superior attributes. Data suggests that if the cost of titanium is reduced by 50 per cent, the annual consumption of titanium could increase by 220 per cent (Norgate and Wellwood, 2006).

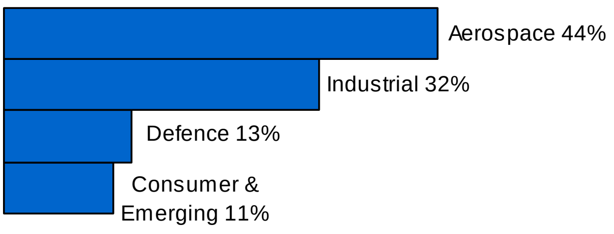
Titanium metal is characterised by its high strength-to-weight ratio and corrosion resistance. It has the highest strength-to-weight ratio of any metal. In its unalloyed form, titanium metal is as strong as steel but 45 per cent lighter, and while 60 per cent heavier than aluminium has twice the strength.

A significant advantage of reducing weight in commercial and military aerospace applications is fuel efficiency. Titanium alloys are used in aircraft engines (up to 20 - 30 per cent of the engine) and in airframes. Approximately 42 per cent of a fighter jet (engine and airframe) is typically made from titanium materials (TZ Minerals International, 2005). The Boeing A380 Airbus uses approximately 67 tonnes in the aircraft body and approximately 10 tonnes in its engines.

The high corrosion resistant property of titanium metal makes it suitable for industrial applications, used in highly corrosive environments, such as chemical processing plants and desalination plants. When titanium is exposed to oxygen in the air and/or water, it immediately forms a stable, strongly adherent protective oxide film that is resistant to many highly corrosive environments, particularly oxidizing and chloride-containing process streams. As long as oxygen is present, the oxide film will self-repair if it undergoes any mechanical damage. Titanium metal is also used in heat exchangers, in propeller shafts, rigging and other parts of vessels exposed to salt water.

In consumer markets, sporting equipment makes use of the benefits of the high strength-to-weight ratio property of titanium metal in the manufacture of a range of sporting goods, such as golf clubs and tennis racquets. Medical and dental industry applications of titanium metal utilise its non-reactive properties (inertness), enabling its use in implants, such as hip replacements, heart pace makers and joint and bone reconstructive surgery.

Titanium Metal End-Use Markets (2010 consumption ~260kt TiO_2)



Source: TZMI

Welding Electrode Fluxing Agent

Rutile and other higher grade titanium dioxide products are important constituents of welding flux, responsible primarily for slag forming properties. The requirements of the slag are to shape the molten weld pool, hold the pool in place during positional welding and protect it from atmospheric contamination, while being readily removable and preferably self-detaching. As such, titanium dioxide is used extensively in ship building and other fabrication applications which employ welding.

Developing Applications: Titanium Dioxide Nanomaterials

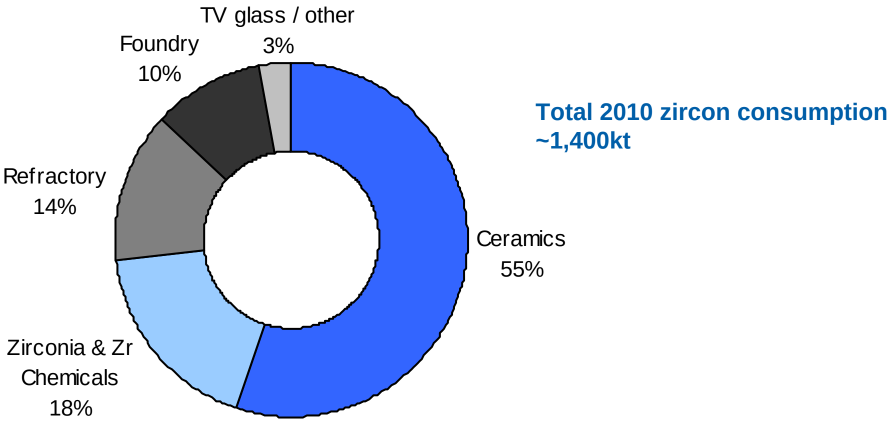
Significant research into nanotechnology in the last decade has shown promising new applications for titanium dioxide. As an example, titanium dioxide nanoparticles are used in dye-sensitised solar cells (DSSC), a relatively new photovoltaic technology which mimics the way plants convert sunlight into energy, although in this case the sunlight is transformed into an electrical current. The potential applications are widespread and range from lightweight low-power markets to large-scale applications.

Other areas of research for the application of titanium dioxide nanoparticles include as an arsenic removal agent in water treatment facilities, cancer treatments (ability to target and destroy cancer cells), and cement that absorbs pollution.

ZIRCON

The largest end-use of zircon is as an opacifier in the manufacture of ceramics based products, including tiles, sanitary-ware and table-ware. A rapidly growing sector for the use of zircon is the production of zirconia, zirconium-based chemicals and zirconium metal. These compounds exhibit many different properties making them suitable for diverse industrial and chemical applications. The other main end use markets for zircon include refractories, foundry, and CRT glass (television glass).

Zircon Consumption by End Use Market in 2010



Source: TZMI

Ceramics

Ceramic applications include the manufacture of floor and wall tiles, sanitary-ware and table-ware. In the ceramics industry zircon is used as an opacifier in glazes and opaque frits (a type of ceramic glass added to glazes for water, abrasian and chemical resistance), and as a whitener in porcelain tiles.

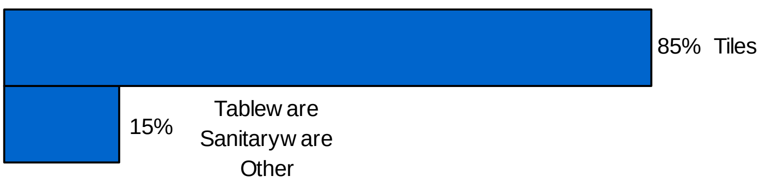
Glazes are typically a silica based glass coating that provides the underlying ceramic body with a waterproof, abrasion and chemical resistant covering. Zircon opacifier is added to the glaze to mask the underlying colour of the ceramic clay body.

Zircon is an effective opacifier due to its high refractive index. Finely milled zircon crystals are able to scatter all wavelengths of visible light therefore making ceramics appear white. An effective opacifier has a refractive index that differs greatly from the medium in which it is suspended. The difference in refractive index of zircon particles (1.96) and glass matrix (~1.5) in a glaze results in the reflection and refraction of light.

Zircon has the additional benefit of its high hardness (7.5 on Mohs scale) making it resistant to scratching and mechanical damage.

Most zircon used in ceramics is consumed by tile producers in the form of a finely milled zircon sand, approximately 1.5 microns in size.

Ceramics End Use (2010 consumption ~770kt zircon)

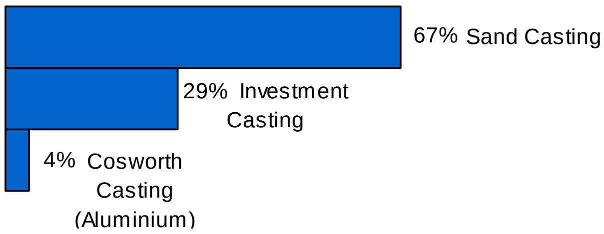


Source: TZMI, Roskill, Iluka

Foundry and Investment Casting

Of the three broad categories of foundry casting techniques: die casting, sand casting and investment casting, the latter two use zircon.

Zircon in the Foundry Industry (2010 consumption ~140kt zircon)



Source: TZMI, Roskill, Iluka

Sand Casting

Zircon sand is ideal for casting a range of molten metals into moulds due its low thermal expansion coefficient, high thermal conductivity (causing it to chill the cast giving a better surface finish) and its non-wetability by molten metal which also improves surface finish and increases the recoverable sand.

Zircon is the most expensive of the moulding sands commonly used and, as such, silica sand (the least expensive), is predominantly used for foundry moulds. Zircon continues to be used where high dimensional accuracy is required.

To improve the finish on the casting, a mould wash can be applied to the sand mould. The main constituent of mould wash is zircon flour and it is the fine particle size and high chill factor (high thermal conductivity) of zircon that improves the surface finish.

Investment Casting

Investment casting is used to make specialty and high precision metal components in aerospace such as jet turbine blades, automobiles and medical instruments.

Investment casting is a technique where the mould is formed around a blank of the part, by applying layers of high quality refractory. Zircon flour and sand form the initial layers of the refractory shells to provide high dimensional accuracy and excellent surface finish, thereby minimizing machining and cleaning of the cast part.

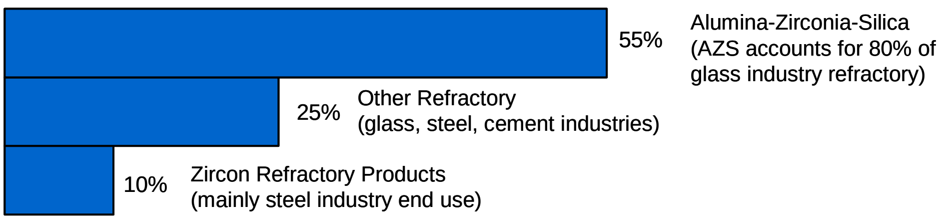
Refractories

Steel production and glass production are the main refractory sectors that consume zircon and zirconia based refractories. Zircon is used in refractory products for its stability at high temperatures and non-wetability against molten metals.

In the steel industry, zircon refractory products include bricks used to line steel making furnaces, injector nozzles and casting channels for refined steel continuous casting.

In glass production, there is no cost effective substitute for zircon.

Zircon in the Refractory Industry (2010 consumption ~200kt zircon)



Source: TZMI, Roskill, Iluka

Zirconia - Fused Zirconia, Zirconium Chemicals

Zirconia is present in the natural form as the mineral baddeleyite. With increased demand for zirconia and decreasing production of baddeleyite, synthetic zirconia is produced from zircon via two different routes – fused zirconia and chemically derived zirconia from zirconium oxychloride (ZOC).

Physical Properties of Zirconia

Property	Value
Specific gravity	5.6 – 6.1
Hardness (Mohs scale)	8.85
Melting point	2,500 – 2,600°C
Refractive index	2.15 – 2.18
Thermal expansion co-efficient	$7.5 – 13 \times 10^{-6}$ °C

Source: TZMI

Fused zirconia products are of lower chemical quality than those produced by chemical processing methods. Fused zirconia is used in higher volume/lower value segments of the market such as refractories, abrasives and ceramic pigments.

Chemical production of zirconia is a relatively high cost process and therefore used in higher value/lower volume applications, such as catalysts used in automotive exhaust systems to control emissions, electronic circuit boards, and piezoelectric sensing devices. In advanced ceramics, chemically produced zirconia is used exclusively in the production of cutting edges, high wearing pump parts and bioceramic parts.

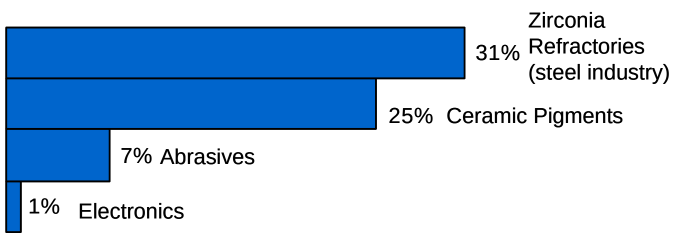
A growing use of chemically produced zirconia is in the telecommunications industry for ferrules for fibre optic cables. The advantages are that fine zirconia powders achieve smoother surface finishes, which is important in achieving high performance connectivity, with the thermal expansion coefficient of zirconia close to that of optical fibre. Zirconia also has the qualities of elasticity and impact resistance.

ZOC – Zirconium Chemicals

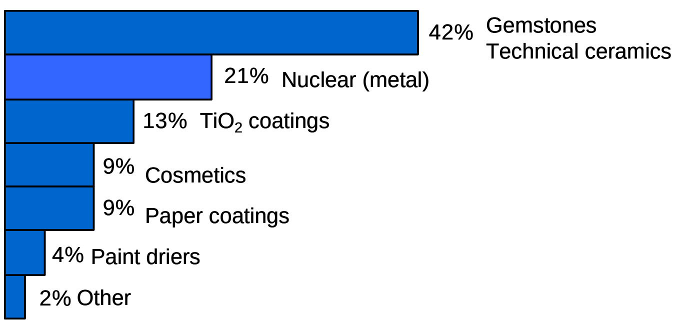
Zirconium oxychloride (ZOC) is further processed to form numerous zirconium chemicals, in particular, for the production of zirconia and zirconium metal. China dominates global production of ZOC with approximately 95 per cent of global production capacity. In China, the biggest market for domestic ZOC is for zirconia used in ceramic pigments. Zirconium chemicals are utilised in a range of manufacturing and end use applications, which include paper coatings, paint driers, antiperspirants, printing inks and paints and catalysts.

Zircon in Fused Zirconia and Zirconium Chemicals (2010 consumption ~250kt zircon)

Zircon in Fused Zirconia



Zircon in Chemicals



Source: TZMI, Roskill, Iluka

Zirconium Metal

One of the major applications for zirconium metal is as a structural material in the chemical processing industry. Zirconium metal exhibits excellent resistance to corrosion in most organic and inorganic acids, salt solutions, strong alkalis and some molten salts. Areas in the chemical industry where zirconium is used include heat exchangers, reboilers, evaporators, tanks, reactor vessels, pumps, valves and piping.

Since zirconium owes its unique corrosion resistance to an adherent, inert oxide film, it is used in condensers.

The other major use of zirconium is for structural material used in nuclear reactor cores. Zirconium metal is used to hold the uranium fuel pellets (fuel bundles) because of its low thermal neutron absorption cross-section, which refers to the ability of a material to absorb thermal neutrons. The lower the thermal neutron absorption, the greater the efficiency of a nuclear reactor. In this regard, zirconium metal is an excellent material.

CRT Glass

Cathode ray tubes (CRT) generate x-rays which must be attenuated to reduce the risk of radiation related health effects, principally cancer. Zircon in CRT glass acts an effective x-ray absorber and has the added benefits of increasing the strength and hardness of the glass.

Whilst the use of zircon in this end application has decreased with the steady replacement of CRT televisions and computer monitors with LCD and plasma screens, zircon is used in plasma screens to enable the manufacture of faceplate glass which is much thinner and of greater dimension.

Zircon Sand Attributes

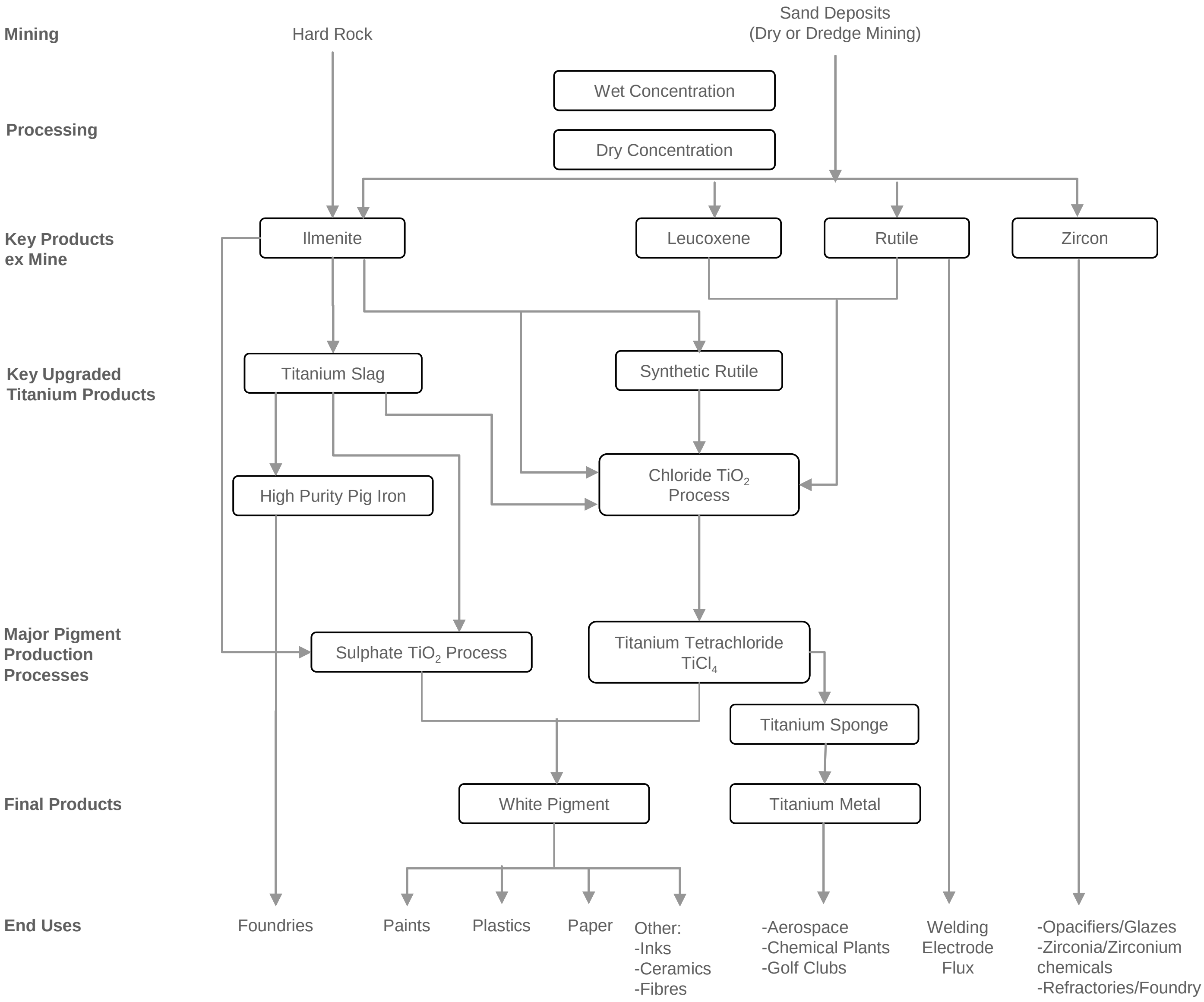
Different zircon sands display varying physical and chemical properties which will influence their end use market applications. For example, key zircon attributes for ceramic manufacture include:

- whiteness index, or ceramic grade;
- iron oxide content below specified levels;
- titanium dioxide content below specified levels;
- aluminium oxide content below specified levels;
- thorium and uranium content typically below 500ppm in the US and other markets; and
- ease of milling, influenced by grain hardness.

Other zircon end use applications have varying product constituent requirements.

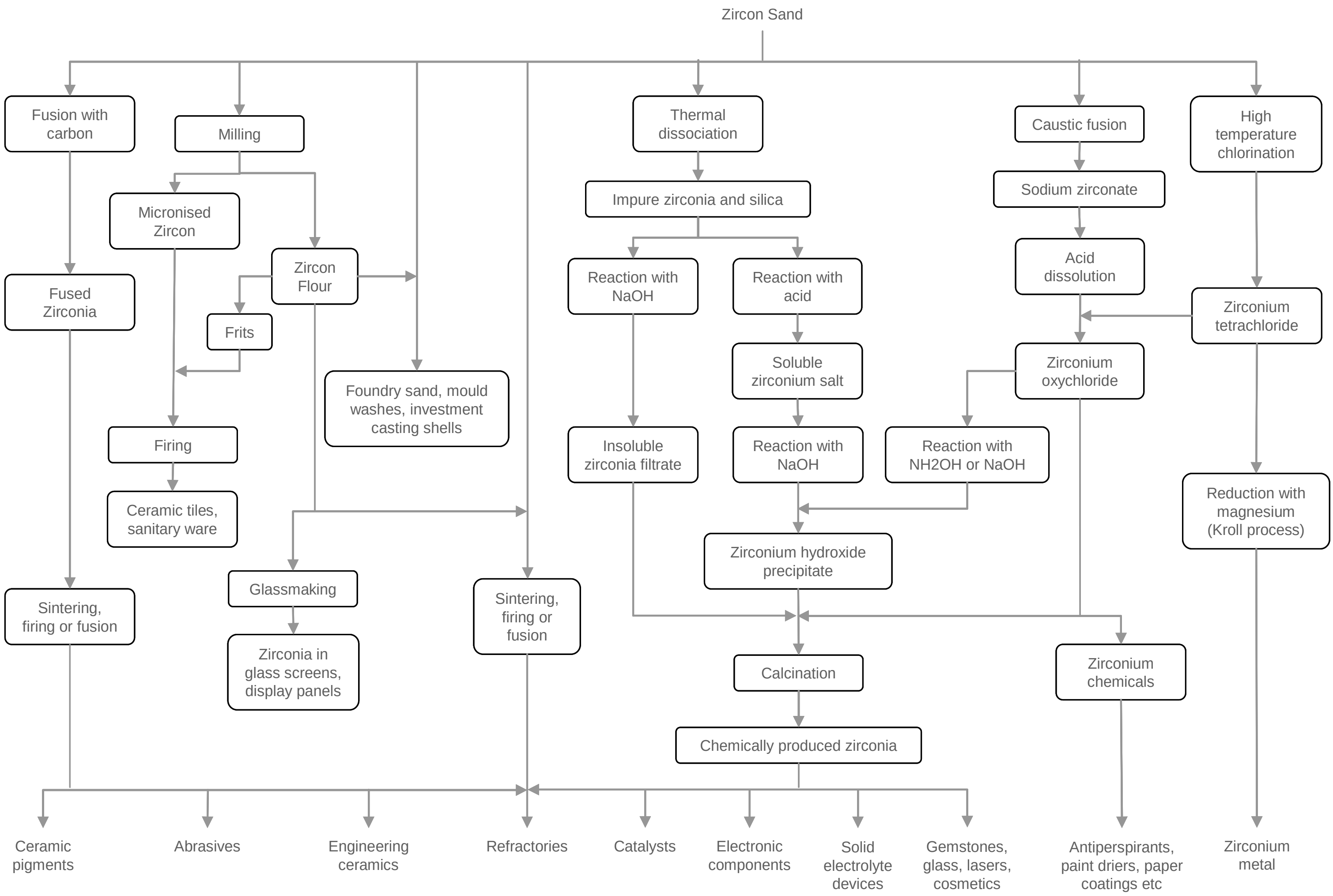
Similar to titanium dioxide, the purchase decision is strongly influenced by product technical considerations.

Appendix 1 Titanium Feedstock Production Processes



Source: TZMI

Appendix 2 Generic Structure of the Zircon Industry



Source: IAEA

References

Information is drawn predominantly from internal Iluka sources. External references relate to the following:

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Other Information

Further Mineral Sands Industry information is available on Iluka's website **www.iluka.com** (refer Mineral Sands Briefing Information – under Investor Relations and Media)

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