The FFC Process for the production of metals and metal alloys
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Overview

• The FFC and Kroll processes
• Current operations
• CP-Titanium and alloys
• Product development and powder production
• O2M plant
• Summary
The Kroll process is energy and capital intensive as well as inflexible

- A process that Kroll himself predicted would be replaced by an electrolysis process
- Uses natural and synthetic rutile and titanium slags as feedstock
- Batch process, limited by the ability to cool the reactor
- Product has only one form: sponge cake
- Significant yield losses due to iron and carbon contamination
- Sponge cake is crushed and then sent for either gas atomisation, melting or casting.

Source: Roskill 2010
Simple, green and cost effective oxide to metal process (O2M)

- Metalysis is commercialising the FFC process for production of metals, developed at the University of Cambridge in 1997. Extensively protected via 19 families of patents and trade secrets.

- The FFC process reduces metal oxides to metals via electrolysis, using a metal oxide cathode, a graphite anode, and a molten salt. Only by-product is CO/CO₂.

- Can produce alloys from their respective metal oxides entirely in the solid-state.

- The FFC process can produce a turnkey product for existing processors.
Current operations are focused on commissioning

**Research Cells**
2005 - Present
- 10 g samples
- Up to 1000 g of CaCl$_2$

**Development Cells**
2008 - Present
- 2-6 kg samples
- Up to 400 kg of CaCl$_2$

**O2M Plant**
Commissioning in progress
- 100 tonnes per annum
- Salt recycling
Feed shapes can be tailored for specific product streams
Product is low in oxygen and other interstitial elements

- Chemistry of product direct from development cell
- Produced at kilogram scale
- Using all different feed shapes
- Product not post processed other than light cleaning with water
- Not an optimised product

<table>
<thead>
<tr>
<th></th>
<th>Oxygen (wt.%)</th>
<th>Carbon (wt.%)</th>
<th>Nitrogen (wt.%)</th>
<th>Hydrogen (wt.%)</th>
<th>Iron (wt.%)</th>
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<tbody>
<tr>
<td>Sample 1</td>
<td>0.14</td>
<td>0.027</td>
<td>&lt;0.01</td>
<td>&lt;0.003</td>
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<tr>
<td>Sample 2</td>
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<td>0.018</td>
<td>&lt;0.01</td>
<td>&lt;0.003</td>
<td>0.11</td>
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</tbody>
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Unique and exotic alloys can be formed with new capabilities

- A significant portion of titanium sold is alloyed
- The workhorse alloy is Ti-6Al-4V
- Must be proven by any new process

Advantages over Kroll:
- Can use heavy stabilising elements
- Can produce pre-alloyed material directly from reduction process
- Avoid segregation via melting
Ti-6Al-4V supersponge can be produced directly from the cell

- Work has focused on preform preparation, reduction parameters and alloying characteristics
- Blend TiO$_2$, Al$_2$O$_3$ and V$_2$O$_5$ powders
- Preforms pressed/extruded/cast and sintered
- Similar reduction to CP-Ti
- Many techniques transferred from experience with CP-Ti
Exotic alloy additions can create master alloys and meltless products

Master alloys

- Have made Ti-Ta and Ti-Mo alloys
- Could reduce the number of melting steps to achieve homogenous alloys

Meltless products

- Experimented with Ti-8V-5Fe-1Al and other difficult alloys
- Other alloys using tungsten have been made
Metalysis proposes some lucrative initial market entry points

**FFC Ti Product**

- **Beads for direct consolidation**
  - **Wire/sheet**

- **Melt / Powder Feedstock**
  - **Gas Atomized TGA powder**
  - **VA Re-melt feedstock**
  - **Hydride-de-hydride feedstock**

![Diagram of product flow](Image)
A meltless product can create new opportunities for titanium use

- Direct consolidation of FFC-Ti product into mill product (rod, sheet or wire) will by-pass many process steps in the existing value-chain
- Powder metallurgy processes are maturing and can provide methods of direct consolidation
- Such a route would be highly disruptive to the current supply chain
- Development needs to be collaborative and product oriented
Flowable titanium powder is produced directly from a FFC cell
Oxide to Metal (O2M) plant has been built

- A novel plant, protected by 6 patent families, has been designed and built.
- It is commercially viable scale to produce tantalum metal and demonstrate titanium production.
- The design is modular and scalable, so that capital investment can match market demand.
Summary

• The FFC process is a patented and proven technology capable of producing metal powders.

• Metalysis has built a production plant:
  • Capable of 100 t of tantalum
  • It is capable of producing either tantalum or titanium

• Establish a revenue generating tantalum business

• Continue titanium product development and refine commercialisation strategy