Exploiting the FFC Cambridge Process

A simple one-step electrochemical technology in which metal oxide is reduced to metal powder is currently being scaled up for the production of a wide range of metals, including tantalum and zirconium.

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The FFC Cambridge process, patented globally in 1998, is a novel electrolytic method for reducing metal oxide to metal in a molten salt. Although originally developed for titanium, the process economics indicate that other metal powders, including chromium, tantalum, silicon, cobalt, molybdenum, vanadium, tungsten, and niobium, can be produced at a fraction of the current cost.

In the 1950s, the Kroll process produced titanium commercially for the first time, and for the next 40 years millions of dollars were expended searching for a less expensive technology. Kroll had actually predicted that his process would be replaced by an electrolytic process, and finally, in the late 1990's, the FFC Cambridge process was discovered in the Materials department at Cambridge University. A simple one-step electrochemical method that reduces metal oxide to metal powder, it is currently being scaled up for the production of a wide range of metals beyond titanium, including tantalum and zirconium.

This article describes how the process was discovered, how it works, its limitations, and the alloys that can be produced.

History of Fray-Farthing-Chen

Working in the Materials department at Cambridge University in the early 1990's, Derek Fray, Tom Farthing, and George Chen were investigating methods for eliminating the oxide film from the surface of titanium. The work yielded an unexpected and very dramatic result: They found that if they applied an electric current, they could convert the titanium oxide directly to metal. Further work showed that molten-salt electrolysis could convert samples of titanium dioxide directly to titanium metal (Fig. 1).

The simplicity of the process surprised the team, who were amazed that the phenomenon had not already been discovered. In fact, the main reason for this was that they were using a titanium oxide cathode, an idea that had not been previously considered because it is an electrical insulator. The revolutionary discovery became known as the FFC Cambridge Process, taking its name from the inventors and their university.

A great deal of the subsequent research has concentrated on titanium. However, the process was also shown to work for other metals, including chromium, silicon, tantalum, and other metals traditionally difficult to win from the ore (Fig. 2). In 2000,

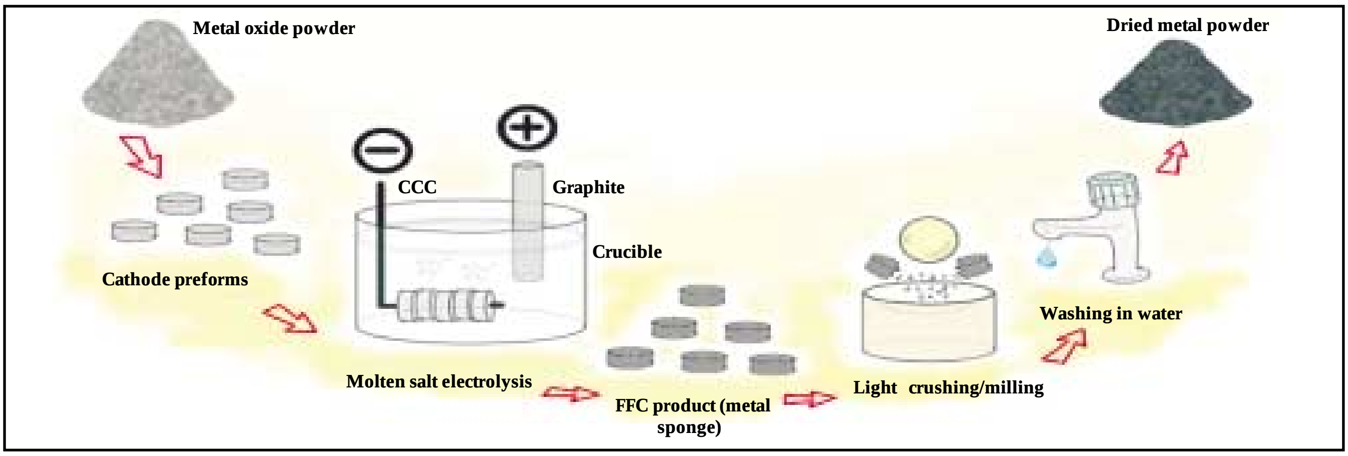

Fig. 1— Schematic diagram showing the stages of the FFC Cambridge process.

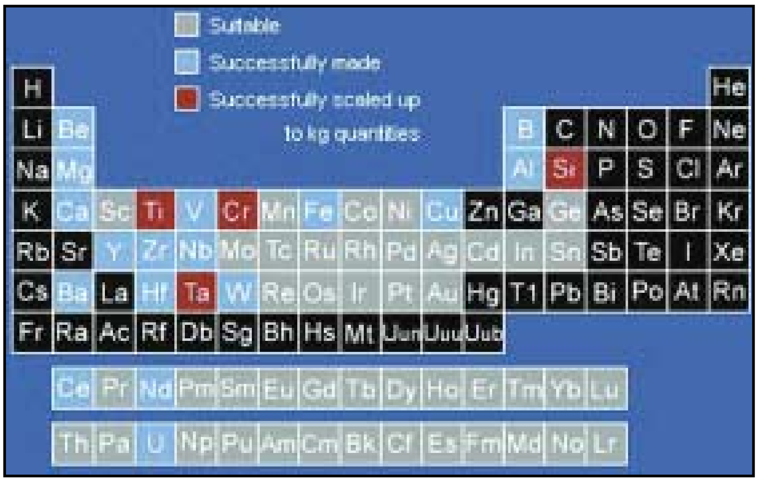

Fig. 2 — Several metallic elements have been successfully produced as metals or alloys by the FFC Cambridge process.

Metalysis Ltd. was set up to exploit the technology for the production of non-titanium metals and alloys. The company has the sole rights for every other element and element combination, and is in the process of securing funding for commercialization.

How it works

The beauty of the FFC Cambridge process is its simplicity. A molten salt acts as the electrolyte for the electrochemical reduction of a metal oxide to metal. The metal oxide powder is contained in the cathode, and is directly converted into metal by electro-deoxidation. Oxygen ions carry the current across the cell, and gas is evolved at the anode, leaving pure metal at the cathode. For many metals, the product can simply be ground to a powder.

In principle, any metal that exists as an oxide can be produced, and at much lower cost than conventional techniques. The capital cost of equipment is far below that of an electric arc furnace needed to produce metallic silicon, or reaction vessels for the handling of liquid sodium in tantalum reduction (Fig. 3).

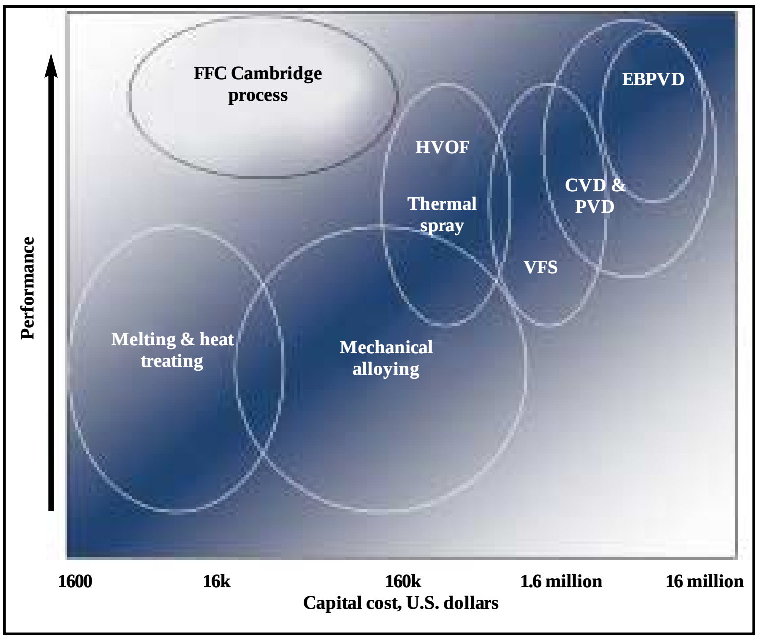

Fig. 3 — Performance and cost considerations for the FFC Cambridge Process and other alloying technologies.

The process also has a very low environmental impact, and operates at low temperatures, in the range 550 to 850°C (1020 to 1560°F). Early analysis work has shown it to compare very favorably with traditional extraction techniques in energy efficiency. The only solvent is a salt, typically calcium chloride, which has the toxicity of table salt. The only byproduct is comparatively low levels of carbon dioxide.

The technology reach

The process is being scaled up, and Metalysis is currently operating a rig capable of processing up to 10 kg of metal. The next level will be a plant with an annual capacity of 20 metric tons per year.

Metal powders with unique morphologies and in a range of particle sizes that are not easily achieved by traditional processes may be produced without difficulty. Metal oxide powders are typically much easier to grind than the pure metals, and hence the oxide feed into the FFC Cambridge process can be very fine. The oxide powder is then converted directly into metal powder, thus allowing control of the particle size distribution of the metal through manipulation of the oxide.

Limitations of existing processes

Existing alloy production processes, such as casting for ingot production or gas atomization for powders, are firmly established in the metals industry. Their general flexibility has led to the exploitation of existing alloys, but it must be remembered that today's alloys are themselves optimized for existing production processes.

Furthermore, non-fusion methods of alloy production, such as mechanical alloying, are limited in the range of metal combinations that can be successful. The FFC Cambridge process offers a unique capability that not only complements existing processes, but also has potential for the creation of a new breed of alloys that could not be produced by any other economic means. It makes possible alloys combining high and low-melting temperature metals such as aluminum-tungsten, finely divided immiscible metals such as uranium-chromium, and metal-matrix composites.

The potential to design entirely new alloys is extremely wide ranging, and makes it worthwhile to consider metal combinations that have previously received scant attention. The range of metals and nonmetals that can be alloyed by the FFC Cambridge process is daunting, but phase diagrams, thermodynamic modeling tools, and simple predictive tools such as 'Structure Maps' can help to pre-select alloys that might offer performance advantages.

Thermodynamic limitations

Some alloys are difficult or impossible to create by fusion processes, because the melting temperature of one element may be greater than the boiling temperature of the other. Binary metal combinations with extreme melting temperature differences, such as tungsten-cadmium, are therefore practically impossible to fuse successfully.

This is true of all metal alloys in Fig. 4 that are colored from yellow to red. Although picking specific alloys that might offer performance advantage is the focus of future work, the potential corrosion performance of FFC zinc-base powder coatings, or the creep performance of FFC magnesium alloys, offers intriguing possibilities.

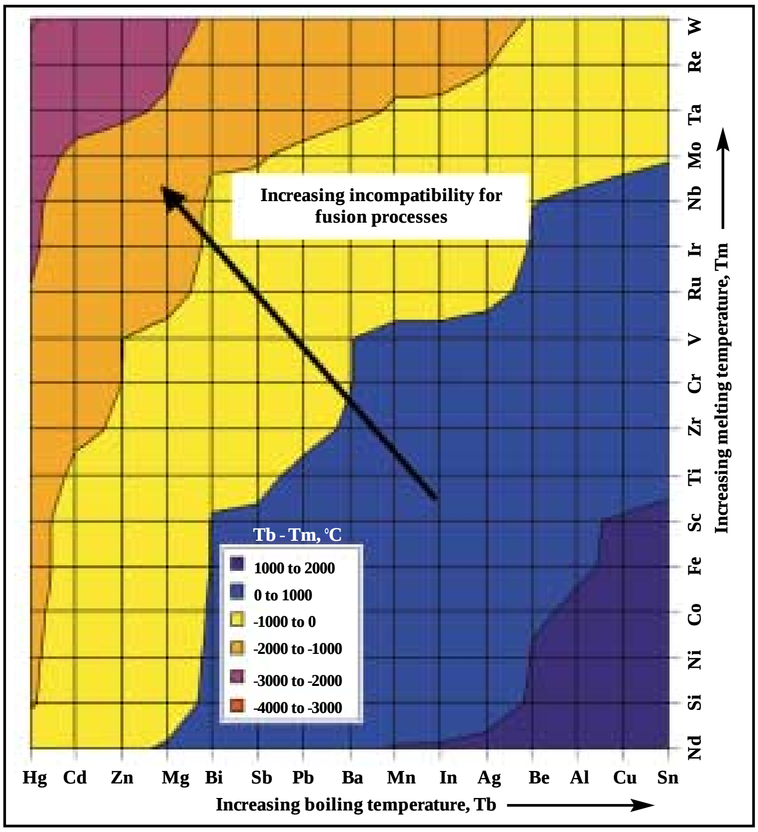

Fig. 4 — Some alloys are difficult or impossible to produce by fusion processes, because the melting temperature of one element may be greater than the boiling temperature of the other.

FFC process opportunities to replace conventional methods

Application	Alloys	Conventional alloying route
Superconductors	Nb_3Sn, NbTi, etc	Melting or powder metallurgy
Permanent Magnets	Nd-Fe-B, Sm-Co, etc	Melting, powder metallurgy
Structural Alloys	Al, Mg, Be, Ni, Co	Melting
Medical	Ti, Ta, Co	Melting or powder metallurgy
Catalysts	Pt, Pd, etc	Melting

Alloy production

The FFC Cambridge process can produce alloys of most metals without melting. Metals of very different melting points can therefore be alloyed together, overcoming some of the problems of conventional techniques. This offers the potential not only for FFC alloys for direct use in components, but also for FFC alloy feedstock for more conventional alloy production methods. For example, tungsten-based FFC alloys could be created with optimized melting temperatures for compatibility with ingot metallurgy-based tungsten microalloyed systems, enabling improved homogeneity.

It may also be possible to form new alloys that have been predicted in theory but have been impossible to produce via conventional thermal routes. The energetics and kinetics of the process form a unique environment for the production of new materials. Furthermore, the microstructure of the FFC alloys is not determined by a previous melting step, and this is of particular interest for those alloy systems for which the as-cast microstructure is poor. Indeed, the unique fine-grained microstructures possible in FFC alloys may well offer unique performance attributes unequalled by conventional process metallurgy.

The FFC Cambridge process is still new, but developmental work has established its potential for a range of commercial applications. Although new alloys offer a means for exploitation of the process, existing alloy systems can also be improved. For example, alloys such as the superconducting NbTi, the magnetic alloy NdFeB, and the shape memory alloy NiTi, have all been successfully produced by the FFC Cambridge process.

The largest growth area for neodymium-based rare earth magnets is in powerful drive motors for electric cars, driven by the requirement for reduced emissions from automobiles. Typical projections for permanent magnets suggest an increase from around US$10 million to US$200 million by the end of the decade, for a global market of three million electric cars. However, for this market to be filled by high-energy, rare-earth magnets, the cost of producing them must be significantly reduced.

A detailed study by consultants Oakdene Hollins concluded that the manufacturing cost of neodymium-based magnets could be significantly reduced by the FFC Cambridge process. This results from replacing the current neodymium alloy manufacturing step with mixed oxide reduction, and applies to all the conventional processes – powdered, melt-spun, and hot-rolled.

Clearly, permanent magnets are just one market opportunity, but it is a good indication of the potential for replacing or complementing existing technology. Other areas of potential application are included in the table above.

Novel lightweight structural alloys based on aluminum, magnesium, or beryllium could offer unique capabilities. Beryllium-based alloys, for example, could be created without fusion by a process for which containment of oxide is quite straightforward. Unique aluminum or magnesium alloys combined with high melting-temperature metals might well offer performance advantages over existing systems. The unique capabilities of the FFC Cambridge process requires detailed review, and this will be the focus of an upcoming joint study by Metalysis and TWI. This work will demonstrate some key features of several alloys, bringing exploitation of novel FFC alloys one step closer to commercial reality. ■

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