Titanium – 21st century

High strength, lightweight titanium with unmatched corrosion resistance and outstanding biocompatibility could infiltrate our lives over the next century in applications ranging from cutlery to cars. Dr Martin Jackson of Imperial College London, UK, investigates

A number of disruptive technologies are focused on elevating titanium's status to a commodity metal. In the future, widely available and cheap titanium could provide developing countries with affordable water desalination metal. prostheses to help cope with an ageing population.

With environmental legislation increasingly emphasising a reduction in carbon emissions, there is a growing need to reduce weight. Both the defence and automotive sectors could therefore benefit from a source of low cost titanium, primarily to replace steel in a wide variety of components. Initially, this would be on rapid deployment equipment, lightweight tanks and armour, and heavy-duty vehicles, such as buses and tractors, as well as in axles, drive shafts, suspensions and exhaust systems. The next market would be mass-produced family vehicles – the 'holy grail' for the titanium industry.

Two kilogrammes of titanium produced by Metalysis Ltd using a novel extraction process – the FFC Cambridge process

Down with the costs

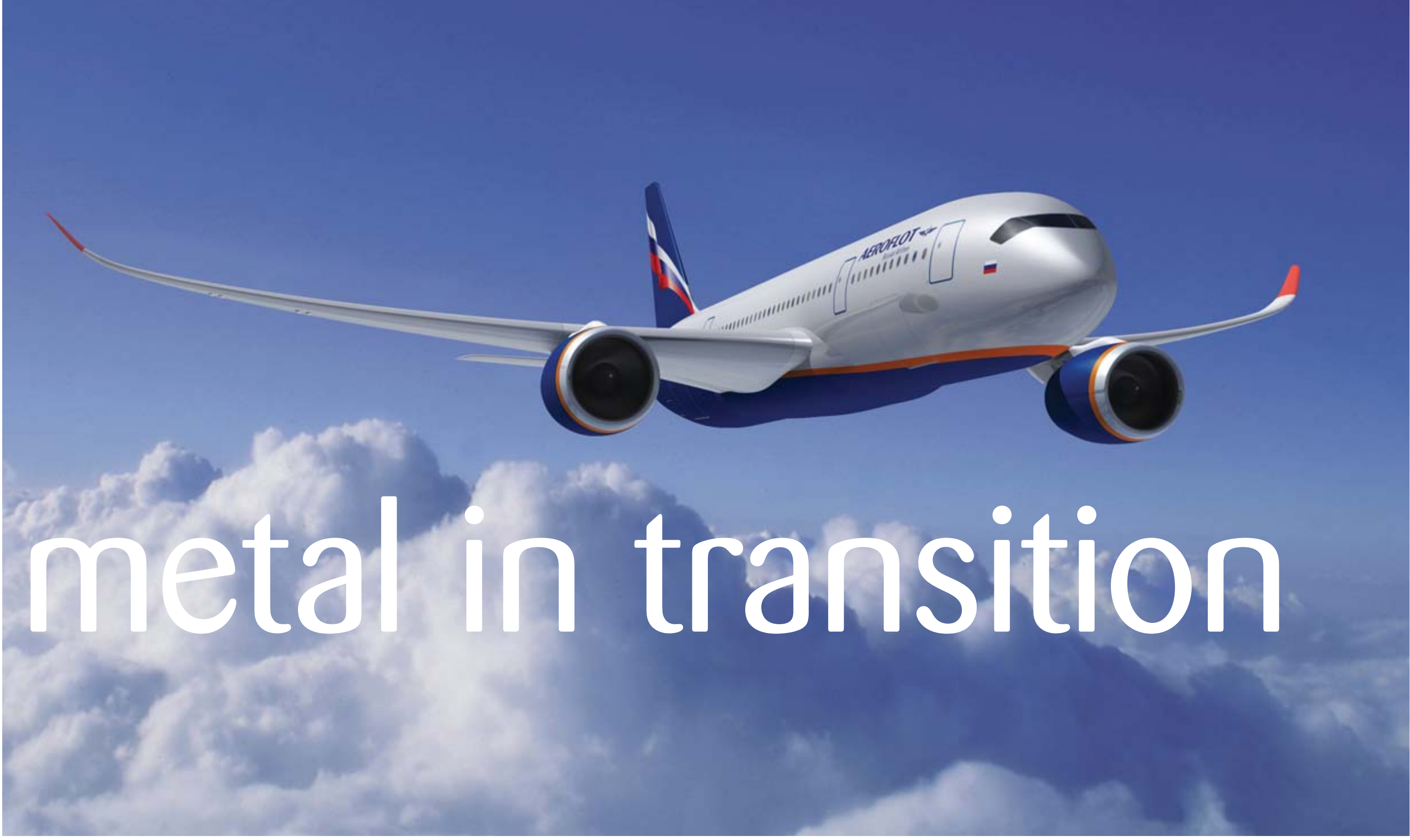
Today, the major drawback of titanium is its high cost. The price of a mill product is in excess of £25/kg (mild steel is £5/kg). This is principally due to titanium's strong affinity for oxygen, which creates challenges both during extraction and downstream processing.

The dominant extraction process at present is a metallothermic reduction method, developed by Wilhelm Kroll 60 years ago. Although it is a slow batch technique, it accounts for less than 40% of the final mill product cost. Downstream processing of the titanium sponge Kroll product, which involves double or triple vacuum arc remelting (VAR) to ingot prior to thermomechanical processing, has the largest bearing. Hence, a low cost extraction alternative to the Kroll process alone is insufficient to provide a substantial economic step change. If the transition metal is ever to break into the family car market, the key lies with improving the downstream, powder-to-product technologies.

Movers and shakers

To meet the increasing demand of the cyclical aerospace sector, and perhaps to invest in a lucrative stockpile, titanium producers have started to scale-up (or bring back online) their sponge and melting capabilities. China intends

metal in transition

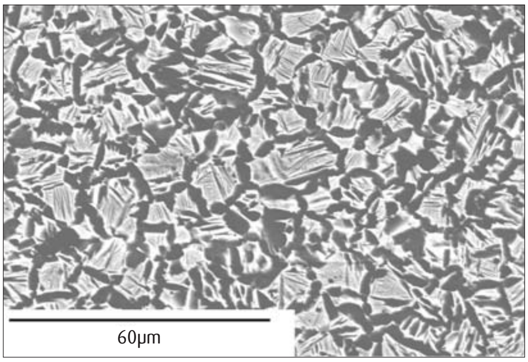


to increase its annual sponge capacity from 15,000 to 120,000t by 2010. With the current annual global production capacity at only 130,000t, China is set to have a major influence on the titanium market. To put this into perspective, the steel industry produces such volumes every hour.

Over the next decade or so, the majority of titanium production capacity will be required to manufacture aircraft and turbine engine components (with the remainder supplying the chemical process industries). This is because the next generation of fuel-efficient civil airliners, such as the Boeing 787 Dreamliner and Airbus A350-XWB (see main image), will consist of a carbon fibre composite fuselage and wings. Up to 20% (by weight) of titanium will be employed as fasteners and couplings, due to the material's superior galvanic corrosion resistance, compared to aluminium and steel, when in contact with graphite.

In fact, Airbus, Boeing and Rolls-Royce plc have negotiated long-term supply agreements with titanium producers in the USA, such as the Titanium Metals Corp (TIMET), and VSMPO-AVISMA Corp (currently the largest producer).

Non-aerospace and emerging markets may suffer from this increased titanium usage in the skies. Encouragingly, many of these potential market sectors, such as defence and automotive, will not require the grades or purities specified by the aerospace industry and the associated high prices.

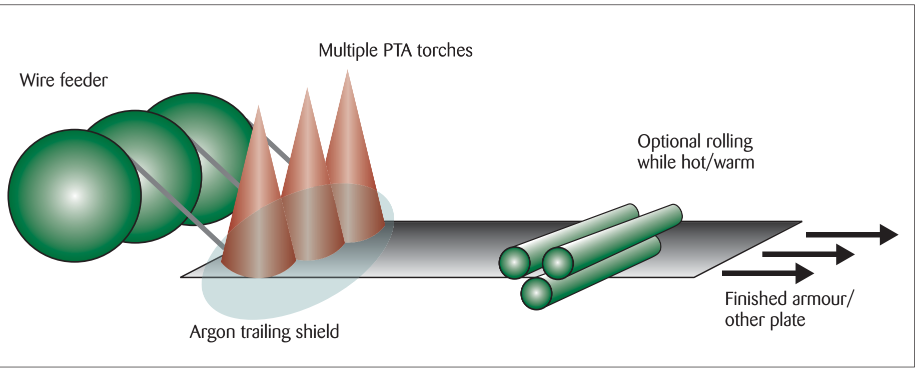


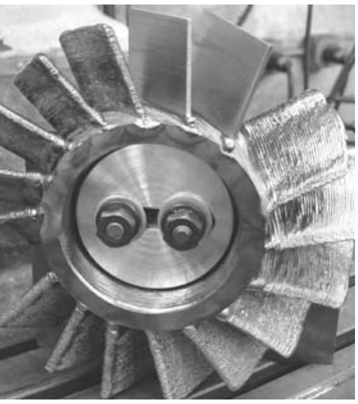
Stepping up

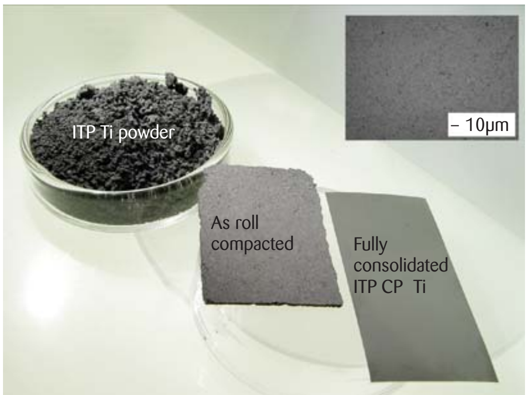
Over the last few years there has been an increased worldwide effort to provide a step change in the economics of the supermetal. This was ignited in the UK in the late 1990s by Derek Fray, Tom Farthing and George Zheng Chen at the University of Cambridge, who discovered an electrochemical reduction process to extract oxygen from TiO_2 to produce low oxygen titanium metal (the FFC Cambridge process).

Such a potentially useful technology inspired the US Defense Advanced Research Projects Agency (DARPA) to fund research in the UK into understanding and developing the process further. A positive outcome is the ease with which the high strength – beta (body centred cubic allotrope) alloys are produced. Scientists at Imperial College London, UK, exploited the process to produce a Ti-10W alloy (see image, above) that has possible biomedical applications. The alloy choice was audacious because tungsten is

Main image: Airbus A350-XWB will have a carbon fibre fuselage and wing structure. Left: Backscattered electron micrograph of Ti-10W alloy produced by the FFC Cambridge process at Imperial College London, UK







Top: Schematic representation of the MER-DuPont innovative multi-head plasma transferred arc downstream processing of titanium wire into armour plate. Above left: Demonstrator component produced by plasma transferred arc rapid manufacturing. Above right: International Titanium Powder's titanium powder, compacted to strip and then sintered to a fully consolidated sheet product

strictly prohibited from titanium production facilities, as the refractory element will not melt during the VAR stage, leading to high-density inclusions in the expensive ingot.

The image demonstrates how the solid state FFC Cambridge process is effective at generating homogeneous fine grained microstructures of both conventional and novel chemistries, even with slow diffusing elements such as tungsten. Such processing advantages are being further exploited to produce shape memory NiTi based alloy chemistries as an alternative to conventional melting routes, which have caused segregation problems.

Five years ago, the FFC Cambridge process was one of around 20 techniques that it was claimed would provide a viable, cheap extraction alternative. Now, in 2007, there are five genuine contenders that could to rival the Kroll process. Two of the technologies, BHP Billiton's Polar method and Norsk Titanium's De-Ox technique, are derivatives of the FFC Cambridge process. Last year, Metalysis Ltd in the UK acquired the Polar process, establishing a new joint venture company (provisionally called Metalysis Titanium Inc) that aims to 'rapidly achieve market penetration and production of titanium and bulk titanium alloy products'.

USA-based Materials and Electrochemical Research (MER) Corporation's electrolytic reduction of a composite oxide/carbon anode is a solid state extraction process that has received strong US Government backing. The entrepreneurial MER Corporation has formed a consortium with DuPont, the world's largest producer of TiO_2 pigment.

In 2006, DARPA awarded MER-DuPont £3 million to develop and scale-up their titanium powder production to around 225kg per day. The team is aware of the demand for low cost conversion of raw powder product to saleable components. They are developing rapid manufacturing capabilities based on a plasma transferred arc (PTA) heat source on either a wire or powder feedstock. The image (left) schematically illustrates a multi-feed PTA arrangement to produce titanium armour plate while the image (bottom left) shows a demonstrator component made by PTA rapid manufacturing.

International Titanium Powder's (ITP) Armstrong process (where gaseous $TiCl_4$ is reduced as it is injected into molten sodium) is intended to be a commercial source of powder by as early as next year. The company is further down the pathway to commercialisation than other novel process routes and aims to become the world's largest titanium producer by 2010.

While there are slight concerns with the low tap density of ITP powder and the need for an additional plasma spheroidisation step to improve consolidation, preliminary trials at Oak Ridge National Laboratory and AMETEK are encouraging. The powder has been successfully consolidated to fully dense product via a range of non-melt downstream routes, such as extrusion, vacuum hot pressing and direct roll compaction, plus sinter to sheet (see image, bottom, right).

In the mid-1850s, aluminium was a luxury metal. Emperor Napolean III and Queen Victoria even dined with aluminium cutlery. With the development of the Hall-Herault process, the price and usage changed dramatically. In fact, today we wrap our sandwiches in aluminium foil. Will advances in the above technologies have the capability to generate a comparable step change in the economics of titanium?

Further information

Dr Martin Jackson, Royal Academy of Engineering/EPSRC Research Fellow, Department of Materials, Imperial College London, UK. E-mail: martin.jackson@imperial.ac.uk.

With thanks to

Andrew Fenn (Metalysis Ltd)
Jim Withers (MER Corporation)
William Peter and Craig Blue (Oak Ridge National Laboratory)
Clive Scorey (AMETEK Inc)