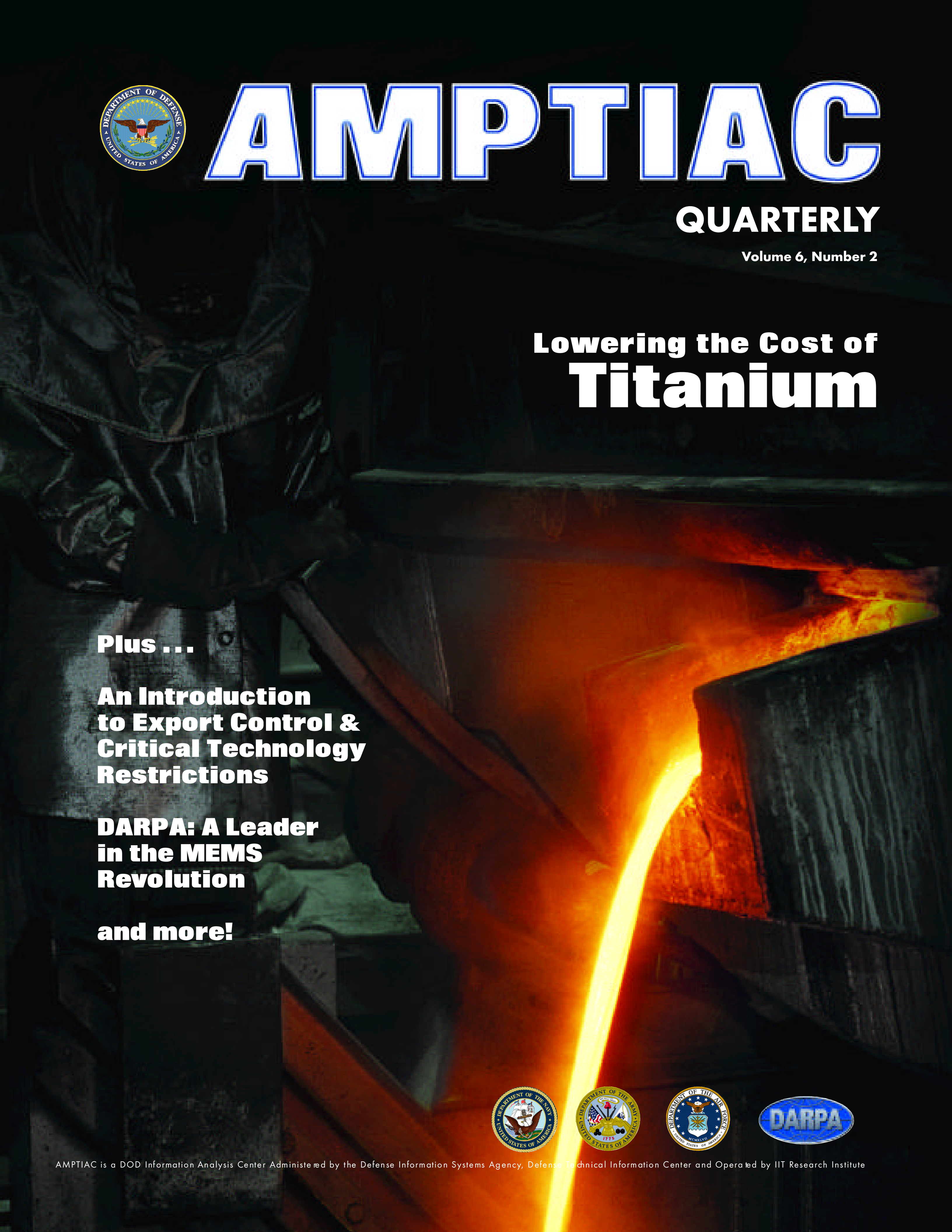

AMPTIAC

QUARTERLY

Volume 6, Number 2

Lowering the Cost of Titanium

Plus . . .

An Introduction to Export Control & Critical Technology Restrictions

DARPA: A Leader in the MEMS Revolution

and more!

AMPTIAC is a DOD Information Analysis Center Administered by the Defense Information Systems Agency, Defense Technical Information Center and Operated by IIT Research Institute

Editorial: AMPTIAC at the Crossroads

For the highly observant among our readership, you may have noticed that this is the first issue of the newsletter in quite some time that does not sport a theme of any kind. Referred to as a "general issue" by our staff, it represents the more traditional format of the newsletter as it was published from our beginnings in the fall of 1996 through calendar year 2000. However, our newsletter paradigm has shifted so rapidly in the past fifteen months that it would be closer to the truth to call it revolutionary rather than evolutionary. Four consecutive themed issues – computational material science (two issues), aging aircraft, and most recently, nanotechnology – I can vouch for our entire staff that it was a busy and challenging year!

I would like to take this opportunity to thank everyone who has responded so positively to our recent special edition newsletter on nanotechnology. We are greatly encouraged by all the feedback: so much so in fact, that we are now in the planning stage for our next special edition newsletter, with several more concepts on the drawing table. Our hope is to make these special editions semi-regular occurrences, through which we intend to highlight a critical or emerging technology of prime interest to our readership. Interspersed between such special editions, we will continue to publish our general issues, as there never will be a shortage of late-breaking developments throughout the materials and defense communities. It is through this balance that AMPTIAC will continue to promote the activities and achievements in materials and related technologies, while also bringing noteworthy topics to the forefront on their own merits.

The developments with our newsletter are only one aspect of AMPTIAC's continuing growth. In the nearly six years since our inception, we have evolved from a merger of five predecessor organizations (MMCIAC, MIAC, CIAC, HTMIAC, and PLASTEC), operating in parallel under one roof, each under the guidance of it's own technical director; to a fully integrated information center serving the materials and processes needs of the entire materials and defense communities. In recognition of this milestone, the last vestiges of our segregated beginnings are being phased out. With the full integration of our technical and information services, AMPTIAC moves forward as a singular and united voice of the DOD's materials and technology interests. If you peruse our directory page, you will see that it reflects much of this change.

While most of these changes will be transparent to all but those who are most intimate with AMPTIAC's operations, their effects will become quickly apparent to those who seek our services. AMPTIAC will be an even more responsive partner, providing timely, efficient, effective support to our DOD, government, and industrial clients in the areas of directed materials support, technology transfer, technology insertion, and information services. Moreover, AMPTIAC will serve as the advocate for critical technologies, raising awareness and bringing them to the attention of the community.

Lastly, the Newsletter, or Quarterly as we have now come to calling it, is at a crossroads as well, representing both an ending and a beginning. This is certainly the case here. This issue also marks the passing of the torch, as we bring new leadership to its helm. After two years overseeing the operations of the newsletter, I am handing over the reigns to our new Editor-in-Chief, Wade Babcock. Wade has been an instrumental force behind many of our themed issues in the past year and veritable fountain of creativity. He has helped forge this new vision for our most visible publication, and shares my commitment to serving you, our reader, as the clarion for reliable, relevant, and cutting edge information in materials and technologies. I wish him the best of luck in this great new adventure and ask that you give him the same enthusiasm and support that you have afforded me. Here's to a bright future!

My sincerest thanks,

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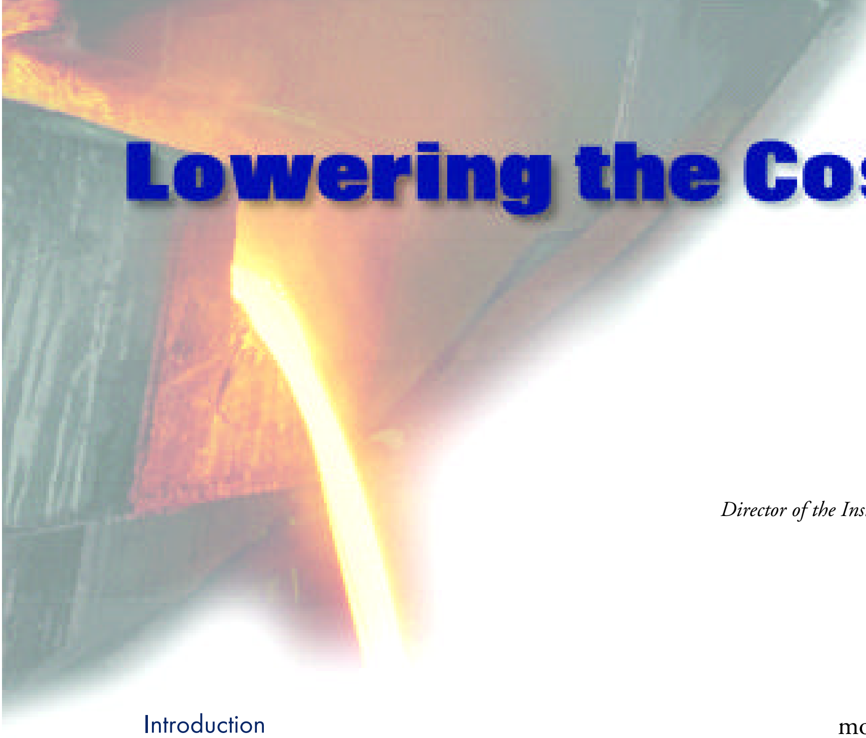

Lowering the Cost of Titanium

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Introduction

To many, the mere mention of 'titanium' might conjure up images of an SR-71 Blackbird streaking through the upper reaches of the atmosphere at amazing speeds. Movie enthusiasts might envision the nearly indestructible space shuttle fleet in *Armageddon*. Discovered late in the 18th century, the engineering potential of titanium was not fully realized until the invention of the Kroll Process in 1948, making titanium available and feasible for defense and industry endeavors[1,2].

What makes titanium so attractive to designers and engineers? Titanium is lightweight, corrosion resistant, and has high strength. The density of titanium is about half that of copper and nickel and approximately 60% of stainless steel. Aluminum, magnesium, and beryllium are the only base metals that are lighter than titanium, none of which come close to titanium in mechanical performance (except beryllium with respect to stiffness). The strength of titanium and titanium alloys ranges from ~205 MPa (30 ksi) to ~1585 MPa (230 ksi).

Titanium exhibits the highest strength to density ratio of all metals to 550°C (1020°F) (see Figure 1). In many environments, particularly those where oxidizing conditions exist, it is more corrosion-resistant than stainless steels and copper alloys, especially when subjected to saltwater.

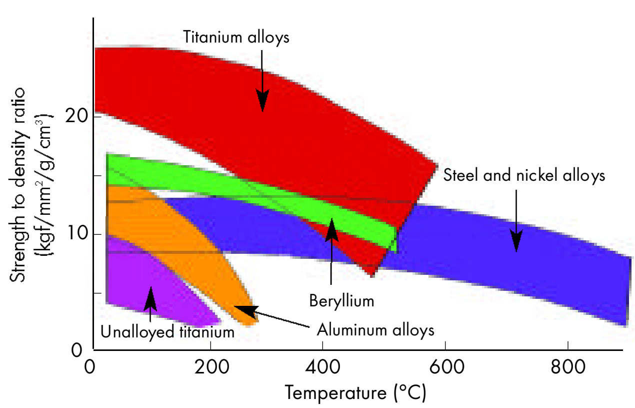


Figure 1. Strength to Density Ratio vs. Temperature of Various Metals[3]

Other potentially useful design characteristics are its low thermal and electrical conductivity, good ductility, excellent fracture resistance, non-magnetic property, non-toxicity, bio-acceptability, cryogenic properties, shape memory properties, and hydrogen affinity (for hydrogen storage). Titanium is very customizable through alloying and microstructural manipulation, which can be tailored to improve performance of a wide range of applications. In fact, titanium alloys often provide designers the best combination of mechanical properties available among metals.

The Economics and Market Potential of Titanium

Those of us with the disease "titaniumitis" believe that all of the wonderful properties of titanium approach those of "unobtanium," a popular (and fictitious) material desired in many designs. Why is titanium not more widely used than say aluminum or steel? Is it a rare and precious metal? No, titanium is the fourth most abundant metal in the earth's crust (0.86 % by weight) behind aluminum, iron, and magnesium. The answer is cost! Titanium is difficult to extract from its ore, difficult to process, and difficult to fabricate. Just accounting for the extraction and processing costs to produce ingot, titanium is ~30 times more expensive per pound than steel and ~6 times that of aluminum. The cost gap for titanium widens when fabricating components and structures. Table 1 shows a cost comparison of the various stages of metal production.

If titanium were as cheap to produce as steel or even aluminum, performance standards on nearly everything we use would be much higher than what we see today; supersonic jetliners could be commonplace, automobile fuel efficiency would be substantially higher, structures would be safer, and so on. Most experts agree that the world production of titanium is much too small given the outstanding combination of favorable properties. With current production at ~50,000 tons (2001), one estimate puts titanium production and use at ~1/20th of its current potential world volume[5]. This severe under-utilization of titanium is easily understood when considering the cost drivers.

Historically, titanium has experienced anemic growth when compared with aluminum and stainless steel alloys. The high cost of production limited the use of titanium to applications requiring high performance or where life cycle cost analyses justified its use. The aerospace and defense communities stimulated initial development of titanium alloys in the early 1950's. Aircraft development during the Cold War was performance-driven without much regard to cost. A radical example of this was the SR-71 Blackbird reconnaissance aircraft, with over 90% of the structure being titanium.

The growth potential and cost cutting initiatives of titanium were severely limited by the dependence upon the cyclic nature of the aerospace industry, with the market experiencing 4-5 year cycles of boom and bust. During boom periods, users were only interested in rapid access to material, leaving very little time for development of low cost techniques; bust periods had few resources available for low cost techniques[5]. Cost conscious markets, such as the automotive industry, are reluctant to commit to titanium because of the unpredictability of the cost fueled by the boom and bust economics. However, with world production of 60 million vehicles annually, even 1 lb of titanium in 50% of the vehicles produced would increase titanium use by 30%, helping to stabilize the cost and reduce dependence on the aerospace industry.[4]

Cost cutting potential and initiatives as shown in Table 1, every stage of titanium production except the mining of ore has tremendous impact potential on the final cost of titanium products. Regarding ore mining, the cost of ore is highly dependent on demand, thus cost reductions will naturally result from a major increase in the demand for titanium products. When considering cost reduction, it is strategic to focus on the early stages of production, where any realized cost advantages would be carried through all production stages. The cost of metal extraction from the ore is approximately 20 times that of steel on a 1-to-1 weight basis, but roughly 11 times when accounting for the density advantage of titanium (less titanium would be required to perform the same function as steel).

In an effort to reduce the cost of producing titanium and other metallic structures the Metals Affordability Initiative Consortium (MAIC) was formed. It is comprised of a team of aircraft and jet-engine manufacturers, material suppliers, and aircraft component suppliers; and directed by the Air Force Research Laboratory's (AFRL) Materials and Manufacturing Directorate[6]. As part of this program, significant efforts are currently underway to reduce the cost of titanium products, many of which are covered in this review.

Low Cost Extraction Initiatives

Shortly after the commercialization of the thermochemical Kroll process in the 40's and 50's Dr. Kroll himself predicted that an electrochemical process would soon make titanium production much more cost competitive:

> "It might…..be fair to say, that titanium will be made competitively by fusion electrolysis within the next 5 to 10 years."[7]

This prediction has yet to be commercially realized, making the Kroll and Hunter[8] (similar to Kroll using Na in place of Mg) processes the norm even today. Unfortunately, thermochemical processes, such as the Kroll and Hunter processes, hold little potential for significant cost reductions beyond current technology.

Electrochemical extraction is still considered a key technology needed to significantly reduce the cost of titanium. Major advantages of electrochemical extraction are reduced energy consumption, automation, and continuous production. Following the evolution of the steel and aluminum industries, if a viable electrochemical extraction process were developed for titanium then there would be tremendous potential for evolutionary technological improvements and optimizations. As the process matures, it would facilitate continual cost reductions.

Electrolytic Extraction of Titanium

Since the invention of the Kroll process, much research has been directed in an attempt to develop an electrolytic extrac-

Table 1. **Cost of Titanium – A Comparison[4]**

	Steel	Aluminum		Titanium		
Production Stage	\$/lb (\$/in^3)	\$/lb (\$/in^3)	Factor to Steel	\$/lb (\$/in^3)	Factor to Steel	Factor to Aluminum
Ore Extraction	0.02	0.10	5	0.30	15	3
Metal Refining	0.10 (0.028)	0.68 (0.066)	6.8 (2.3)	2.00 (0.33)	20 (11.8)	2.9 (5.1)
Ingot Forming	0.15 (0.043)	0.70 (0.068)	4.7 (1.6)	4.5 (0.73)	30 (17)	6.4 (10.6)
Sheet Forming	0.30-0.60 (0.085-0.17)	1 – 5 (0.098 – 0.49)	3.3-8.3 (1.2-2.9)	15 – 50 (2.44-8.14)	50-83 (29-48)	10-15 (17-25)

tion process. Many technical and economic challenges have hindered success in this endeavor, including: [5]

- Incomplete understanding of molten salts in fundamental electrochemistry[5]
- Boom-bust economics of the titanium industry[5]
- Difficulty developing adequate oxide diaphragms to divide the cell into anolyte and catholyte compartments,
- Not enough analysis of experiments performed on non-diaphragm cells.
- The multivalence of titanium ions requires a separation between anolyte and catholyte to avoid alternating oxidation and reduction with low current efficiency.
- In the chloride system, some electrolyte gets trapped in the Ti crystals, requiring additional processes to remove the electrolyte. This operation decreases the purity of the produced Ti.
- Fluoride systems did not receive enough financing because of the preference toward the chloride system.
- No real financial sponsor outside the titanium producer community.

Current research focuses on overcoming the technical challenges identified above from decades of electrochemical research on titanium extraction.

FFC Cambridge Process

A novel new approach to electrochemical extraction is the patented Fray-Farthing-Chen (FFC) Cambridge process. Schematically shown in Figure 2, this process does not require the metal oxide (TiO_2) or chloride ($TiCl_4$) to be dissolved in the electrolyte as with traditional electrolytic processes; it remains in a solid state during the electrolytic process. This new technique shows tremendous promise and it has been projected that it could reduce in the cost of titanium extraction by as much as 50% or more by 2010.

Like many useful inventions, the FFC Cambridge Process was discovered by accident. Originally, Derek Fray, Tom Farthing, and George Chen were experimenting with electrolysis of titanium in molten $CaCl_2$ to remove oxygen impurities from titanium. Oxygen impurities (dissolved oxygen interstitials in a titanium matrix) can strengthen the material, but at the same time make it brittle, so the intent was to purify titanium metal and remove the dissolved oxygen (note that the dissolved oxygen impurity is not the same as the TiO_2 layer that a titanium surface immediately develops upon exposure to air).

The purification experiment revealed something quite unexpected; the titanium oxide layer was converted to low oxygen titanium. This process was counterintuitive because TiO_2 is usually considered an insulating material, so the researchers did not even expect the electrolysis experiment to affect the TiO_2 layer. They then tried the same experiment on pure pellets of TiO_2 and produced pure titanium sponge with a similar structure as that produced using the Kroll process. The researchers discovered that the slight removal of oxygen from TiO_2 through electrolysis resulted in Magnelli phases, which are good electrical conductors, ultimately enabling the complete electrolysis of TiO_2.

The FFC Cambridge process has the potential to revolutionize the titanium industry. Potential and real advantages over the Kroll and Hunter processes include:

- Low cost feed material (TiO_2 instead of the costly $TiCl_4$);
- $CaCl_2$ is readily available, inexpensive, non-toxic, water soluble, and has a high solubility for oxygen;
- Rapidly produced titanium sponge (~1/5th the time required using the Kroll process);
- Potential to directly produce alloys by mixing oxides of various metals;
- Potential for continuous production which enables significant cost reductions (Kroll and Hunter processes are batch processes requiring significant time, labor, and resources);
- Potential to produce high purity titanium and alloy powders for use in near net shape powder metallurgy technologies.

The FFC Cambridge process has yet to reveal any major pitfalls for scaling up. In fact this new process may revolutionize metal extraction for numerous metals including zirconium, niobium, chromium, vanadium, and numerous other periodic groups (III-X) and rare earth elements.[9, 10, 11]

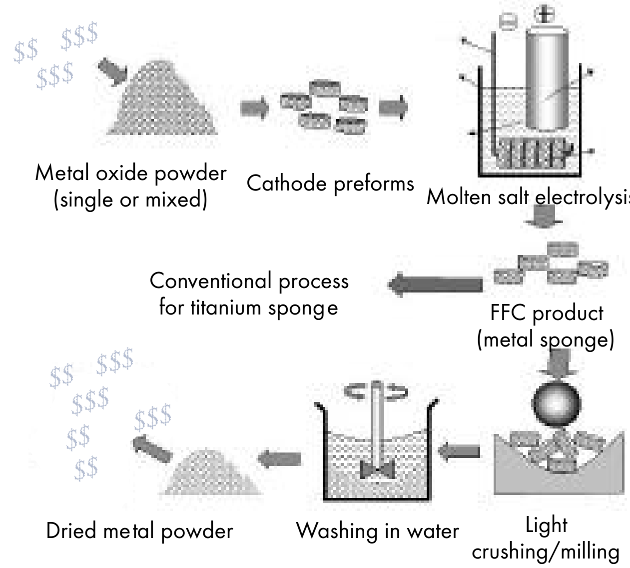


Figure 2. Schematic of the FFC Cambridge Process (courtesy D. Fray, Cambridge University)

Low Cost Melting Initiatives

Ingot and Wrought Stock

Introduced in 1952, the vacuum arc re-melting (VAR) process is still the most common process for alloyed titanium and aerospace commercially pure (CP) grade titanium (unalloyed)[12]. Analogous to the Kroll and Hunter processes for extraction, VAR is still utilized because a commercially viable alternative has not emerged to completely replace this expensive process. The disadvantage of VAR is that the material must be double- and sometimes triple-melted to produce adequate purity and microstructure. Much of the research in this area is focused on replacing or optimizing VAR.

Electron beam hearth-melting (EBM) has seen limited success and is the primary method for producing industrial CP grades[13]. EBM and plasma hearth-melting (PAM) are strong candidates for producing high quality alloys for jet engine applications, reducing the likelihood of inclusions seen with double melt VAR. Advantages of EBM and PAM are improved quality, scrap recycling, and shaped ingot production. These technologies are beginning to be utilized for alloy production by the major titanium producers (Timet, Allegheny Teledyne-Oremet Facility, RMI Titanium).

Additional initiatives to reduce cost of these technologies are to optimize process control and develop process-modeling capabilities in order to optimize quality and minimize cost. A strategy that is gaining momentum is to eliminate this step altogether and use near-net shape technologies such as investment casting and powder metallurgy processes.

Casting

The high cost of titanium often forces designers to look for ways to minimize waste material often associated with the more conventional manufacturing processes such as machining.One cost reduction strategy that has received considerable focus and development resources is on near-net shape techniques such as casting, powder metallurgy (P/M), superplastic forming (SPF), and forging.

Often, cast metals show much lower mechanical properties as compared with wrought metals, however, cast titanium properties compare very well with their wrought counterparts and in some cases, exceed those of wrought, especially when considering crack growth and fracture properties. This makes casting of titanium products a very attractive option to reduce cost and optimize engineering performance. However, titanium casting technologies have historically experienced technical challenges that have hindered development and widespread use.

Recent technology and process improvements (many through the MAIC program) have enabled significant improvements in the quality of cast parts, helping to meet stringent aerospace specifications. Investment casting comprises most of the current capacity, however, some development has taken place to enable permanent metal-mold die-casting of titanium[14]. Advantages of metal-mold casting include improved microstructure and elimination of ceramic inclusions and alpha-case (a shell of alpha-phase titanium), however, this technology is size- and shape-limited.

Investment casting technologies have matured nicely. Induction skull-melting (ISM) and VAR melting produce titanium melts with minimal contamination. Ceramic and metallic mold materials have been selected to minimize reaction with the titanium melt. Hot isostatic pressing (HIPing) is used to improve the density by eliminating porosity, thus improving the overall quality of the casting. Investment castings can be quite large and complex, combining many components into one complex structure, making them a clear choice for many complex aerospace applications[15]. An additional advantage is that lead times for castings tend to be shorter as compared with conventional processing such as forging and machining.

Information technology initiatives such as computer-aided design and computer-aided machining (CAD/CAM) and process modeling are drastically improving investment casting capabilities and quality. CAD/CAM technologies are being used in conjunction with rapid prototyping to produce complex parts for making investment molds. Process modeling techniques are being developed to optimize gating and risering of investment casting molds to optimize microstructure, reduce shrinkage and voids, and improve quality[12].

Other research on titanium investment casting technologies includes novel cold crucible induction melting and centrifugal casting. Induction technologies enable the charge to be superheated. When combined with centrifugal casting, this promotes the filling of thin section cavities, improves properties, dimensional accuracy, form, and detail and reduces the cost of melt stock as compared with VAR investment casting. Some induction technologies enable partial to full levitation of the charge, reducing the cost of melt stock and reducing waste.[16, 17]

Low Cost Processing Initiatives

Forging

Computer and sensor technologies have been incorporated into forging processes to control heating time and strain rate, improving die filling and reducing forging defects. Isothermal forgings are also being investigated and developed, taking advantage of technology since this process lends itself to more control and flexibility.[18] Process modeling and control technologies are also used to time impacts enabling metadynamic and static recrystallization and to dissipate adiabatic heating.[12]

Powder Metallurgy (P/M)

P/M techniques afford designers the ability to produce significantly complex near-net shape parts at a potentially significant cost savings, with very little wasted material. Traditionally, P/M techniques required high volume runs (generally above 10,000 pieces) and relatively small parts to be cost effective. This is due to the high cost of equipment for P/M processing. Also, concerns remain regarding the quality and properties of P/M produced parts, especially from lower cost blended elemental powders (BE). The much higher priced prealloyed (PA) powder, produced by gas atomization (GA), or the plasma rotating electrode process (PREP) lead to mechanical properties equivalent to cast-and-wrought products [19-22]. Good news is on the horizon on several fronts of P/M technologies.

Powder Production Technologies The lower cost BE titanium powders coming from titanium sponge produced through conventional Kroll and Hunter processes contain chloride impurities. Chlorides inhibit production of 100% dense compacts, resulting in reduced weldability and fatigue properties.[23, 24] Recent developments in titanium extraction (FFC Cambridge Process) and powder production are aimed at reducing the cost and improving the quality of titanium powders.

Research is currently being carried out on an Army Research Lab small business innovative research (SBIR) project to produce very low cost titanium powders from cleaned machine turnings using the hydride/dehydride (HDH) process.[21] The aluminum-titanium (AlTi) process is one such approach for

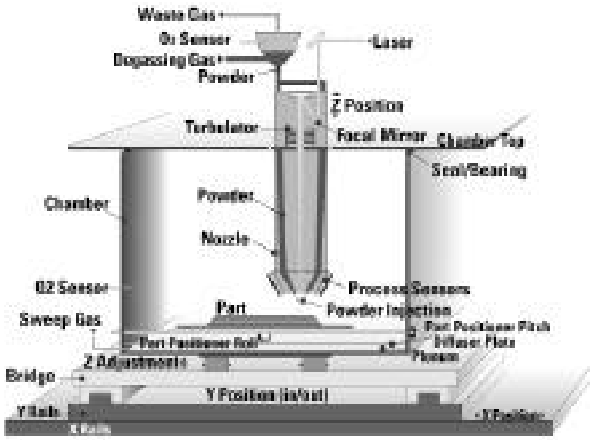


Figure 3. **Schematic of Laser Additive Manufacturing Process (courtesy AeroMet Corp., www.aerometcorp.com)**

Figure 4. **Laser Additive Manufacturing (courtesy AeroMet Corp., www.aerometcorp.com)**

producing these powders. It involves a reaction of TiO_2 with fluorine salts followed by reduction with aluminum. This process originally also produces very low chloride levels, however, it is not widely available.[22] Significant efforts are also being applied to optimize and adapt an elevated temperature metal hydride reduction (MHR) process developed in Russia[25] in conjunction with ADMA Products, Twinsburg, Ohio. This new process involves mechanically alloying (in a high energy ball mill) TiO_2 and/or $TiCl_4$ with CaH_2 to induce chemical reactions that produce Ti.[26]

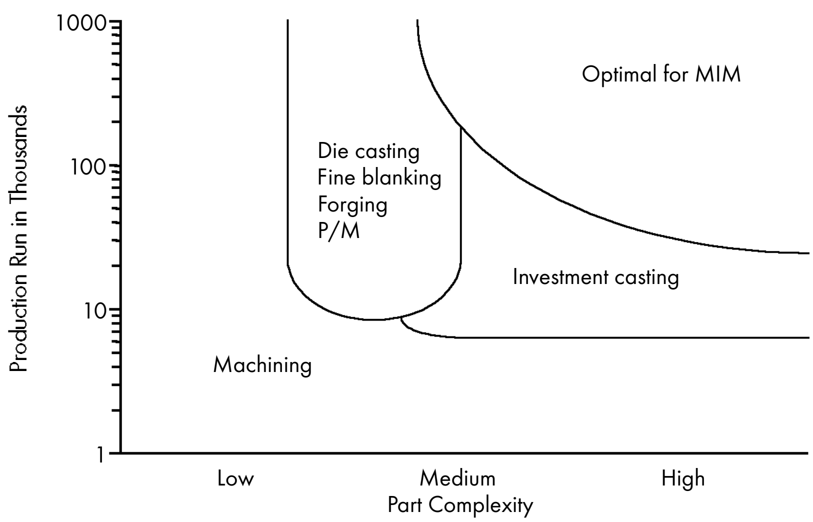
Laser Forming One of the most significant developments in the application of metal powders is the use of laser forming technologies to produce highly complicated, low volume parts (Figures 3 & 4). Advantages of this technology include short lead times, high complexity, significant cost savings, moderate size, and greatly reduced machining requirements. Costs are projected to be 15-30% less than conventional approaches and up to a 75% reduction in delivery time for low run, high complexity parts.[27]

Metal Injection Molding (MIM) Metal Injection Molding, also known as MIM, is an analog of plastic injection molding. It is a high-volume technology, where powdered metal is mixed with a binder and injected into a mold, de-bonded, and sintered to produce small complex parts at a low cost (relative to other techniques). Figure 5 shows where P/M and MIM processes are beneficial from a cost perspective. MIM technology currently exists with world volume at about 3 to 5 tons of parts per month. Recent and current developments are focused on improving density and properties through selection of improved binders (effective, but not adding significantly to the oxygen content of titanium) while maintaining its cost effectiveness. Titanium MIM is poised for substantial growth as a low cost means of producing high volume parts. A primary driver for this growth will likely be development of the low cost powder technologies previously discussed. [20, 28]

Traditional Powder Metallurgy Techniques Traditional P/M techniques include press and sinter, elastomeric bag cold isostatic pressing (CIP), and ceramic mold or metal can HIP. These processes can be carried out using BE or prealloyed (PA) powders.

The BE approach is potentially the lowest cost titanium P/M process available. Unfortunately, parts are limited in size and complexity, as well as less than 100% of theoretical density, which would adversely affect mechanical properties. Recent developments, such as using hydrided powders, have enabled the fabrication of BE parts to over 99% of full density, resulting in significantly improved properties. Further studies and developments show that this approach may be well suited to reduce the cost of producing automotive parts making titanium more cost competitive with other materials commonly

Figure 5. **Relative Applicability of P/M, MIM, and Other Ti Processes.[20]**



used in many automotive applications.[20]

PA powders are much more costly than BE powders, however, typical P/M parts produced using PA powders demonstrate superior properties than typical BE produced parts. In fact, the properties of both BE and PA parts are beginning to compare well with cast and wrought products, making P/M techniques increasingly attractive and cost effective alternatives to traditional processing.[20]

New P/M Research and Development Significant efforts in P/M research continue on numerous fronts such as spray forming, rapid solidification, mechanical alloying, and vapor deposition. All of these research initiatives are aimed at exploiting the outstanding characteristics of titanium and its alloys. Some of these processes are aimed at producing new alloys that improve and customize properties; alloys that cannot be developed through traditional processes.[20]

Superplastic Forming (SPF) and Diffusion Bonding (DB)

SPF/DB is a technology receiving interest for its potential to reduce cost and improve the structural efficiency of aerospace components. The technology involves the bending and forming of titanium at slow strain rates under temperature and pressure to produce complex geometries at a much reduced cost over conventional processing. SPF/DB requires material that will superplastically form, and many titanium alloys work well using this technology. Current development efforts are attempting to make this process much more predictable and controllable through complex process modeling algorithms.[29]

Mass Production Initiatives

As noted earlier, titanium usage remains at depressed levels as compared with its engineering potential. A major factor hindering widespread usage is cost, and it remains high because of low volume and the cyclic nature of the aerospace market. The automotive and other high-volume industries have shied away from titanium because of the prohibitively high cost. If these conditions were to change, then the cost of titanium products would rapidly and dramatically decrease. This is especially true when leveraging the manufacturing ingenuity of high-volume industries to optimize production and life cycle costs of systems.

As the mindset shifts from ultra high-quality and high-performance aerospace applications to mass production applications, many are discovering that costs of titanium components have become much more competitive, in large part because of the ingenuity of the commercial sector. As a result some initiatives are aimed at mass production techniques and how they can apply to existing applications.[4, 30]

Applications and Outlook

Defense/Military

Significant efforts and resources are being expended by DOD to help reduce the cost of titanium and to introduce titanium in applications to improve performance and reduce life cycle costs. MAIC (led by AFRL) is aimed at reducing the cost of metallic components in aircraft by 50% and accelerating the implementation time for these components. Much of the research through MAIC is directed at titanium technologies because of the added emphasis on life cycle costs and performance criteria of aircraft.[6]

The Navy's National Center for Excellence in Metalworking Technology (NCEMT) is investigating a single-melt cold hearth PAM process to help reduce the cost of titanium ingot. NCEMT is also aggressively identifying candidate systems and components that would benefit from the use of titanium. As part of this investigation, they are identifying low cost processes that will help them justify changing to titanium.[31]

The Army is actively and aggressively investigating the feasibility of using low cost titanium armor for combat vehicles. Experimental results are showing that titanium alloys maintain high mass efficiencies compared with rolled homogeneous armor (RHA) across a broad spectrum of ballistic threats. It also shows good multihit ballistic capability. This all equates to improved armor at a potential weight savings of 40% over RHA.[32, 33]

As part of the Army's initiative to transform itself into a lighter, more transportable force, they are investigating numerous other potential applications such as the use of Ti6Al-4V receivers for use in the M240 machine gun.[34] Titanium is also very attractive for personal armor because it possesses excellent ballistic properties and is lightweight.

Commercial Aerospace

Titanium usage in the aerospace community has been widespread for years and will continue to be a material of choice for years to come. In fact, titanium usage continually increases on newer models of commercial aircraft. It is expected that usage will increase even further as unit costs come down and quality improves on new processes.

Industrial Markets

Industrial markets primarily include the energy and chemical processing industries (CPI). This market segment accounts for the largest (~39%) consumption of titanium just ahead of commercial airlines (~36%).[35] The corrosion resistance of titanium makes it an ideal candidate for usage in many energy and CPI applications. Titanium is gaining significant interest in drilling and offshore production systems.[36, 37] It is predicted that the industrial market for titanium will grow 50% by 2010.[35]

Consumer Markets

Consumer markets include automotive, medical implant, sporting goods, and specialized consumer goods such as wheelchairs. Titanium manufacturers are immensely interested in breaking into the family automobile market.

Any significant use of titanium in automobiles would help to significantly stabilize the economics of titanium supply and demand, enabling suppliers to ensure prices and supplies to customers. Immediate potential applications include exhaust systems, drive shafts, connecting rods, valves, valve springs, coil suspension springs, front and rear bumper supports, retainers, lug nuts and studs, shock center rods, sway bar fittings, strut center rods, and wrist pins, just to name a few.[4] One of the most significant uses of titanium in a production automobile is in the Corvette Z06 exhaust system, resulting in an 18 lb. weight savings over the stainless steel version. In life cycle cost studies, Chevrolet estimates that the titanium model will result in lower overall costs due to increased life and a drastic reduction in warranty claims.[38]

Sporting goods manufacturers are very interested in the performance enhancing characteristics of titanium in many applications. One attractive aspect to manufacturers is that sporting goods consumers are often willing to pay a premium for performance and prestige.[39] The corrosion resistance and biocompatibility of titanium has also generated wide interest in the medical community for transplants.

The Future

More and more, engineers are coming to realize the benefits of titanium. This trend will continue and be enhanced through user education – potential consumers need to be made aware of its outstanding properties, emerging lower cost processes, and its potential benefits to the life cycle of new applications. Some have predicted that the 21st Century will be the 'Century of Titanium'. If so, what an exciting journey it will be!

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Where Have All the Tech Directors Gone?

As mentioned in the Editor's introduction on Page 2, AMPTIAC has come a long way since our beginnings in 1996. During those early days, we were charged with integrating four pre-existing DOD sponsored Information Analysis Centers (HTMIAC, CIAC, MIAC, and MMCIAC), and the next year added the mission areas of a fifth center (PLASTEC). Along with these mergers came the acquisition of a tremendous amount of technical reports - nearly 3 1/2 tractor-trailers full!

To ensure continuity of service and customer focus, we initially established five individual technical directors to help oversee and guide our transition-related activities. These technical directors were each responsible for a technical focus area to ensure balanced and comprehensive coverage in the traditional structural materials categories including metals, ceramics, composites, and polymers, but also other nonstructural materials including electronic and optical materials, as well as the whole area of lubricants and fluids.

Since AMPTIAC is now a mature and integrated Information Analysis Center, our original management and technical support structure is no longer needed. To provide better service to our customer base and to ease access to the tremendous amount of technical information available, we are broadening the responsibilities of our technical inquiry services manager, Mr. David Brumbaugh, to be the single point of contact for all customer inquiries. AMPTIAC is responsible for acquiring, analyzing, archiving, and disseminating technical information that covers nearly all classes of materials. We have more than 220,000 technical reports that cover the waterfront of materials technologies, including in-service performance. Our technical staff is second to none in that their core competency is to locate materials-related technical information and assist customers with design, materials selection, failure analysis, and the like. If you need assistance or would like some additional information on AMPTIAC products and services, please contact David at 315-339-7113 or email him at dbrumbaugh@iitri.org.