ABSTRACT

The Reinvention of the Ti-6Al-4V Alloy
(From Low Cost Turnings to Component Shape)
by Susan M. Abkowitz¹ and Stanley Abkowitz²

The Ti-6Al-4V alloy is the most commonly used titanium alloy of the titanium industry (70% of all alloys) and generates a considerable annual volume of scrap machining turnings (over 30 million pounds globally). These machine turnings currently find application as partial additions to the titanium ingot melting operations or as alloy additives to steel melts. Although useful, the value of these turnings in such applications is limited. The recycle of machined turnings directly to titanium alloy prime billet or to component shape will offer significant cost reduction.

This presentation will review the technical work underway at Dynamet Technology under Marine Corps. sponsorship to produce a cast shape from innovative casting feedstock composed primarily of Ti-6Al-4V alloy machining turnings. These are specially processed to purify the material of contaminants and uniquely consolidated to high density casting electrodes (feedstock). Chemical analysis, microstructure and the impressive mechanical properties achieved with cast material will be discussed along with the potential for significant cost savings.

This innovative process, in addition to producing low cost titanium components represents the green manufacturing of titanium offering significant energy savings along with highly desirable environmental benefits.

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² Stanley Abkowitz is Chief Executive Officer, Dynamet Technology, Inc.
The Reinvention of the Ti-6Al-4V Alloy

Recycled Ti Turnings to Prime Alloy Product

Stanley Abkowitz, Susan M. Abkowitz

Dynamet Technology, Inc.
Eight A Street, Burlington, MA 01803
www.dynamettechnology.com
The Development of Ti-6Al-4V Alloy
Army Watertown Arsenal Laboratory
1952-1955
June 10, 1954

First Technical Paper on Ti-6Al-4V at Columbia University
Mimeographed Agenda

The Symposium at Columbia (June 9-10, 1954)

Columbia University, Men's Faculty Club
117th St. and Morningside Drive, New York, N.Y.

FIRST SESSION
Chairman: I. B. Jaffe, Watertown Arsenal

1. The Effect of Hydrogen on Ultrasonic Attenuation in Titanium
   C. F. Ting and H. E. Truell, Brown University

2. Effect of Temperature on Slip and Twinning in Titanium
   J. N. Ross, J. W. Perkins, and L. L. Seigle, Sylvania Electric Products Incorporated

3. Effect of Betta Titanium
   F. Albert, New York University

THIRD SESSION - Thursday, June 9, 1954 - 9:00 A.M. to 12:30 P.M.
Chairman: Major H. J. Kofila, Wright Air Development Center

- Fatigue Characteristics of Titanium and Titanium Alloy Rod at Minus 40°F, Room Temperature, and 600°F
  A. I. Blank and J. H. Perri, Chase Brass and Copper Company

- A Basic Study of the Behavior of Titanium Alloys under Repeated Load
  N. D'Appolonia, Carnegie Institute of Technology

- Effect of Strain Rate on the Creep and Tensile Performance of Titanium Alloys
  R. L. W. Marsh, General Electric Company

4. Mechanical Properties of High Strength Tough Titanium Alloys
   S. A. Abkowitz, Watertown Arsenal

SECOND SESSION - Wednesday, June 9, 1954 - 1:30 P.M. to 5:00 P.M.
Chairman: L. B. Haffke, Watertown Arsenal

- The Effect of Hydrogen on Ultrasonic Attenuation in Titanium
  C. F. Ting and H. E. Truell, Brown University

- Effect of Temperature on Slip and Twinning in Titanium
  J. N. Ross, J. W. Perkins, and L. L. Seigle, Sylvania Electric Products Incorporated

- Effect of Betta Titanium
  F. Albert, New York University

FOURTH SESSION - Thursday, June 9, 1954 - 1:30 P.M. to 4:00 P.M.
Chairman: Harold Bernstein, U.S. Naval Gun Factory

- Mechanical Properties of High Strength Tough Titanium Alloys
  S. A. Abkowitz, Watertown Arsenal
Glass Lantern Slides

FOR RELEASE
MONDAY, 17 MAY - AM PAPERS

NEW ALLOY
Hailed By Army
Titanium Compound May Add Striking Power
To U.S. Ordnance

Press Release

Army Announces
New Light Alloy
Equal to Steel

New Arsenal Alloy Weapons
Light, Hard-Hitting, Powerful, yet
with high-strength steels now used
in tanks, and armor plates.

Super-Tough Alloy Formed

FOR Armored Weapons

Cold Rolled Development of a new titanium alloy developed by the Army, named the "New Arsenal Alloy." The alloy has a high tensile strength and is very corrosion-resistant, making it ideal for use in armor plate and tanks. The alloy is being tested for use in various applications, including aircraft and weapons systems. It is believed to be a potential substitute for steel in many ordnance components.

For more information, contact the Public Information Office, Watertown Arsenal, Watertown, Mass., or Extension 452.
Here at last is the complete story on titanium; its technology, its capabilities, its potentialities, and its problems, written by three engineers of the Watertown Arsenal Laboratory, which is the center of titanium research and development for the Armed Forces. These men have not only been pioneers in the research and development of titanium but are intensely interested in the future of the metal.

Although the book is a highly scientific treatise on the metal, each subject has been approached in such a manner that it is readily readable by all who will be in contact with the metal from the front office down to the production line.

The book provides a brief history of titanium. The main portion of the book is devoted to the following subjects: production of the metal; its physical, chemical and mechanical properties; alloying and heat treatment; casting and powder metallurgy; hot and cold shaping; machining and grinding; surface properties; analytical and metallographic techniques; and selection of alloys and applications. Each chapter is accompanied by an extensive bibliography on the subject. The book is now at press and will be ready early in January. The price is $5.50.
The invention described herein may be manufactured and used by or for the Government of the United States for governmental purposes without the payment of any royalty thereon.
U2 - Lockheed Skunk Works

The Lockheed Martin U-2S (Photo Courtesy Lockheed Skunk Works)
“...in outer space, in aircraft, on the ground, underground, on the sea, undersea, on the body and within the body.”

* The Emergence of the Titanium Industry and the Development of the Ti-6Al-4V Alloy,
- Collections & Recollections by Stanley Abkowitz
“On the wall…”

Guggenheim Museum, Bilbao, Italy
“...and off the wall.”
Advantages that led to the widespread use of Ti-6Al-4V

1. From its beginning the alloy was perceived by the manufacturers and the users to be a government-developed, royalty-free alloy.

2. It had the versatility of being both heat treatable and weldable.

3. It could be produced in all mill product shapes such as sheet, plate, tube, bar, pipe, and welding wire (and it offered higher tolerance for hydrogen).

4. It could be readily forged and successfully cast as well as easily machined.
5. With the increasing applications, its mechanical and chemical properties and its fabrication procedures became fully characterized.

6. As it became the basic alloy of choice, recycling of mill scrap was facilitated since the alloy could be segregated, its chemical identity maintained, and significant quantities of a single alloy composition could be economically reclaimed.

The scrap alloy is typically reclaimed by supplementing virgin sponge in melting titanium ingot or used for alloy addition to steel melts.
Titanium History

Available from International Titanium Association
Fast Forward To Low Cost Titanium Efforts
Near Net Shape Powder Metal (PM) Manufacturing Technology
Dynamet’s powder metal CHIP process is used to produce near net shape titanium alloys and MMCs. The PM preforms can also be hot worked to produce forgings and extrusions.
Examples of Cost Saving
Production Missile Components

- **Sidewinder**
  - Dome Housing
  - Ti-6Al-4V
  - CIP+Sinter
  - 45,000 parts
  - 50-70% Cost Savings

- **Stinger**
  - Warhead Casing
  - Ti-6Al-6V-2Sn
  - CHI P
  - 50,000 parts

- **Seeker Housing**
  - Ti-6Al-4V
  - CHI P Process
  - 2,000 parts

50-70% Cost Savings
Current and Emerging Titanium-Based Powder Metal Products
Mill Product Manufacture by PM vs Conventional Ingot Metallurgy

VAR DOUBLE MELT PROCESS
- Titanium Sponge
  - First Melt
  - Second Melt
- Densified, Homogeneous, Alloyed Billet
  - Forging to Billet
  - Raw Material Yield 98%
  - Casting, Extruding, Forging

DYNAMET PM PROCESS
- Titanium Powder Blend
- Densified, Homogeneous, Alloyed Billet
- Raw Material Yield 98%
The Marine Corps Program for Low Cost Ti-6Al-4V Castings for the Expeditionary Fighting Vehicle (EFV)
Low Cost Titanium Feedstock Process

Innovative method for producing low cost Ti-6Al-4V casting feedstock from titanium alloy machine turnings.

Dynamet Technology, Inc.
Eight A Street, Burlington, MA 01803
LCFP Ti-6Al-4V Casting Results

✓ Chemical analyses met applicable specs and were comparable to the baseline Ti-6Al-4V (no tramp elements).

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>V</th>
<th>Fe</th>
<th>C</th>
<th>O</th>
<th>N</th>
<th>H</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM B367</td>
<td>5.50-6.75</td>
<td>3.5-4.5</td>
<td>0.4 max</td>
<td>0.1 max</td>
<td>0.25 max</td>
<td>0.05 max</td>
<td>0.01 max</td>
<td>0.1 max</td>
</tr>
<tr>
<td>Avg LCFP Casting</td>
<td>6.55</td>
<td>4.11</td>
<td>0.21</td>
<td>0.044</td>
<td>0.25</td>
<td>0.014</td>
<td>0.0008</td>
<td>0.049</td>
</tr>
</tbody>
</table>

✓ Tensile Properties met applicable specs and were comparable to wrought Ti-6Al-4V.

<table>
<thead>
<tr>
<th>Material</th>
<th>UTS (ksi)</th>
<th>YS (ksi)</th>
<th>EI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg LCFP</td>
<td>155.3</td>
<td>137.1</td>
<td>12.1</td>
</tr>
<tr>
<td>AMS 4985 &amp; ASTM B367 (castings) Min.</td>
<td>130</td>
<td>120</td>
<td>6.0</td>
</tr>
<tr>
<td>AMS 4928 (wrought) Min.</td>
<td>130</td>
<td>120</td>
<td>10.0</td>
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✓ Projected Cost Savings: 30-60%

Dynamet Technology, Inc.
Eight A Street, Burlington, MA 01803
The Advantage of Using Low Cost Powder *Plus* Scrap Recycle to Produce *Extra* Low Cost Prime Mill Product
Integrated PM/Recycled Ti-6Al-4V

Titanium Machine Turnings

Titanium Powder

SSCP
Solid State Consolidation & Purification
- Isostatic pressing
- Vacuum treatment

Casting Feedstock
Forging Preforms
Extrusion Billet Preforms
Rolling Plate Preforms

The Creation of NuLife Titanium LLC