Flowforming Tubulars Made of Titanium Alloys:
Written by Matthew Fonte, September 2006

Flowforming, Cost Savings:
Titanium alloys continue to be vital for many important defense and aerospace systems but high cost and long delivery times are major factors limiting titanium alloy usage. Offering substantial economical benefits, flowforming is becoming more widely embraced as the manufacturing process of choice in the fabrication of difficult-to-produce thin wall, cylindrical components. Flowforming is often used as a net-shape process, requiring less material to make a part and reducing the costs associated with secondary machining operations. Advanced materials such as titanium alloys are often solely available in forged bar or billet and now can be successfully flowformed into precision tubular parts. Seamless components with high length to diameter ratios, up to 50 to 1, realize the greatest cost savings through the flowforming manufacturing process.

Flowforming, The Process:
Flowforming is a net shape forming process capable of close dimensional accuracies on the component’s diameter, wall thickness, straightness, roundness and concentricity. After a cylindrical work piece, referred to as a “preform”, is fitted over a rotating mandrel, hydraulic force is applied to the outside diameter of the preform by a set of three CNC-controlled rollers. The desired geometry is achieved when the preform is compressed above its yield strength and plastically deformed or “made to flow”. As the preform’s wall thickness is reduced by the set of three rollers, the material is lengthened and formed over the rotating mandrel. This cold work process causes the material’s mechanical properties to increase, while refining the microstructure and orienting the crystallographic texture. Dimensional accuracies are normally achieved well beyond what can be realized through hot forming processes.

Flowforming Machine, with Titanium Pipe

Right of the photo is a pallet with four extruded Titanium preforms on it.

In between the preforms and the flowforming machine is a stack of 24 foot long flowformed 4” schedule 10 pipe.

Economical Benefits:
With the price of Titanium alloys increasing, saving material is paramount. Preforms are typically four times shorter than the final flowformed component. Short preforms can be easily machined from solid billet, heavy wall forgings, extrusions and/or hot isostatic pressed (HIPed) powder material. Machining short preforms saves much material compared to having to machine full length parts. Also, flowforming components to either net shape or near net shape often reduces or eliminates the need for timely and expensive secondary machining operations. Avoiding the need to finish machine a thin wall part can be very desirable as vibration or “chatter” issues are eliminated. This is of particular interest when the material is hardened and, therefore, difficult to machine.

One example of how the flowform process offers cost savings is when Dynamic Flowform Corp. successfully flowformed cradle and recoil tubes for the M777 light-weight 155mm Howitzer guns. This work was performed for the United States Army through the National Center for Excellence in Metalworking Technology (NCEMT). These gun systems will be used by the both the Marine Corps and Army and are made lighter by utilizing Titanium 6Al-4V tubes. Conventionally, the cradle and recoil tubes were produced
by extruding a thick-walled tube, measuring each individual extrusion for roundness and straightness, bump-straightening the extrusion, and then machining the extrusion wall thickness on the inner and outer diameters to meet the final, thin wall tube requirements. By flowforming, Dynamic Flowform has been able to offer the Army a net-shape cradle and recoil tube which eliminates several manufacturing processes and reduces material waste. The flowforming manufacturing approach that Dynamic developed offers the Army substantial cost-savings. Similar costs savings are being offered to the Air Force for flowformed Joint Strike Fighter Titanium 6Al-4V LiftFant™ Center Drive Shaft.

Titanium Alloy Classes:
In addition to flowforming the Ti 6Al-4V material, which is an alpha-plus-beta class Titanium for the cradle and recoil howitzer tubes, Dynamic Flowform has been very busy developing the flowforming of almost all of the other Titanium classes. Because of the strong relationship between the flowforming process parameters, deformation behavior, and final part mechanical properties of the various Titanium alloys, it is necessary to review the classes of Titanium alloys which exist in two allotropic forms: Hexagonal close-packed (HCP) alpha phase and Body-centered cubic (BCC) beta phase. The more difficult to flowform alpha phase is usually present at low temperatures, while the more easily deformed beta phase is present at high temperatures. The temperature at which a given titanium alloy transforms completely from alpha to beta is termed the “beta transus” and is a critical temperature in titanium alloy processing for determining the class of alloys. The different classes of titanium alloys are unique from one another and are highly sensitive in deformation processes such as flowforming. Each class has unique flowforming processing criteria, with different deformation rates and behavior. The developed flowforming process parameters, combined with subsequent thermal treatments, are manipulated for each alloy type to achieve desired final flowforming microstructure and mechanical properties.

Unalloyed Titanium:
Unalloyed titanium typically contains between 99%-99.5% titanium, with the balance being made up of iron and the interstitial impurity elements hydrogen, nitrogen, carbon, and oxygen. Unalloyed Titanium consists of grains of alpha phase. They are easier to fabricate and generally less expensive than alloyed Titaniums. Grade 2 is a common “unalloyed” titanium offering an excellent balance of strength and ductility. The material has good toughness and is very corrosion resistant in highly oxidizing and mildly reducing environments.

Below is a three dimensional cut away of a flowformed Titanium Grade 2 tube. Flowformed material has fine micro-structure in the cross-sectional direction. The grains have been elongated and flattened to create a general “elongated pancake” shape. In the transverse orientation the grain size is very fine (ASTM 12) or approximately 0.0001” average grain diameter. When the tube undergoes a post-flowform anneal, the elongated grains return to a spherical crystal structure. During annealing the high level of stored energy in the microstructure from the flowformed cold work, expedites the recrystalization process, which produces a new grain structure without phase change. In the diagram below, the Longitudinal view is parallel to the center line of the tube; the Transverse view is across the width of the tube and the Radial view is flat-wise on the surface of the tube.
**Alpha and Near-Alpha Titanium Alloys:**
Titanium alloys have a fully alpha structure only if they contain alpha stabilizers such as aluminum, tin, and oxygen. These elements also act as solid solution strengtheners. A typical all-alpha alloy is Ti-5Al-2.5Sn. A typical near-alpha alloy is Ti-6Al-2Sn-4Zr-2Mo. Ti-6Al-2Sn-4Zr-2Mo is often used for forgings and rolled products in jet engines and airframe applications where high strength, toughness, and creep resistance are required.

![Flowformed Ti-6Al-2Sn-4Zr-2Mo](image1)
Longitudinal Cross-Sectional View
Magnification: 500X

![Flowformed Ti-6Al-2Sn-4Zr-2Mo](image2)
Transverse Cross-Sectional View
showing ASTM Grain Size No. 10 or finer
Magnification: 100X

**Alpha-Plus Beta Titanium Alloys:**
These alloys contain both alpha stabilizers and beta stabilizers and can be heat treated to develop a range of microstructures. The “lean” alpha-beta alloys are moderately heat treatable while the “rich” alpha-beta alloys have greater hardenability, and thus can be through-hardened in thicker section by heat treatment. The most important “lean” alloy is Ti-6Al-4V. The “rich” alloys include Ti-6Al-6V-2Sn and Ti-6Al-2Sn-4Zr-6Mo. Ti-6Al-4V alloy is the most widely used titanium alloy of the alpha-plus-beta class, and is also the most common of all titanium alloys, offering moderate strength, good strength to weight ratio and favorable corrosion properties. Alpha-plus beta alloys are typically fabricated at elevated temperatures around 1800 degrees Fahrenheit, near their beta transus temperature. Flowformed Ti-6Al-4V has primary globular alpha grains that have become elongated or stretched parallel to the axis, surrounded by a fine transformed beta structure, also elongated in the direction of metal flow.

![Flowformed Ti-6Al-4V](image3)
Longitudinal Cross-Sectional View
Magnification: 500X

![Flowformed Ti-6Al-4V](image4)
Transverse Cross-Sectional View
showing ASTM Grain Size No. 10 or finer
Magnification: 100X
Near Beta Titanium Alloys:
This family of alloys do not retain 100 percent beta after solution annealing, making them near beta titanium alloys. Some commercial alloys in this classification are Ti 13V-11Cr-3Al which was widely used on the SR-71 Blackbird military airplane, Ti 10V-2Fe-3Al which has been used for the Boeing 777 landing gear, Beta 21s, Ti 15V-3Cr-3Al-3Sn and recently, Ti 5Mo-5V-5Al-3Cr on the VT 22 Bomber. Titanium 35Zr-10Nb alloy is different in that the solution anneal produces a basket-weave transformation microstructure. It is soft and ductile, which is typical for the near beta alloys; and it can be readily deformed. The Ti 35Zr-10Nb has the lowest beta transus temperature of the near beta group. Ti 35Zr-10Nb can be heat treated to achieve a very thick, lustrous black oxide layer. This ceramic layer is dense, homogeneous and exhibits superior wear resistance. Flowformed tubes have been heat treated to achieve the adherent oxide layer.

Beta Titanium Alloys:
Beta alloys contain a balance of beta stabilizers to alpha stabilizers, which is sufficiently high that a fully beta phase microstructure can be retained on cooling. They are generally high strength, high toughness, and improved formability, as compared with alpha-beta alloys; which provides an attractive combination of properties. However, processing and material costs are often quite high. Ti-3Al-8V-6Cr-4Zr-4Mo also known as Titanium Beta C™ is an example of a commonly utilized beta alloy. Beta C™ is capable of achieving a wide range of mechanical properties. In the solution annealed condition, the alloy is very ductile and can be easily cold worked, unlike typical alpha-plus beta alloys. High strength levels can be developed by cold working, solution treating, and aging, or a combination of these processes. This alloy also exhibits very good resistance to reducing acids. The beta alloys are commonly used for springs and fasteners for aircraft and tubing in oil and gas wells and they flowform very well.

Titanium-Boron Alloys:
Scientists and engineers at the Air Force Research Laboratory Materials and Manufacturing Directorate are working to develop and transition a new titanium alloy that has high strength and stiffness as well as low density. This new class of alloys could potentially fulfill the Air Force’s latest needs in aerospace structures, engine components, and spacecraft components. Additions of 500-1000 parts per million of boron helps with the formation of equiaxed alpha, instead of lamellar alpha. Specifically, these changes provide an order-of-magnitude reduction in cast grain size and eliminate rapid grain growth above the beta transus, while retaining strength, stiffness and fracture properties (ductility, toughness, fatigue). These Ti-B alloys thus transcend the boundaries currently limiting manufacturability and enable a radical shift in the manufacturing process paths for the titanium industry; including dramatic reduction or elimination of ingot breakdown enabled by an order-of-magnitude decrease in as-cast grain size; radical innovation in mill processing routines by relaxing current constraints imposed by the beta transus; and new paradigms in secondary manufacturing such as flowforming, rolling, super-plastic forming etc. Ti-B material that have been flowformed and annealed achieved strength levels of 150 ksi Yield Strength, 160 ksi Ultimate Tensile Strength with 26% elongation.

Shape Memory Titanium Alloys:
The term “shape memory alloys” (SMA) is applied to the class of materials that demonstrates the ability to return to some previously defined shape or size when subjected to the appropriate thermal procedure. Generally, these materials can be plastically deformed at relatively low temperatures and, on exposure to some higher temperature, will return to their shape prior to deformation. The phase transformation yields a thermoelastic martensite and develops from a high temperature austenite phase. Upon cooling, the phase transformation reverses itself. The most commercially successful shape memory alloys are Nickel–Titanium alloys, typically 49 to 51% Ni. They have excellent properties such as repeatability of mechanical behaviors, good fatigue life, wear resistance, corrosion resistance and biocompatibility and are often used for nonvascular and vascular stents in biomedical applications. In the aerospace industry, shape memory titanium alloys are used to actuate devices. The shape memory effect is induced in the wires simply by heating them with an electric current, eliminating the need for large hydraulic lines. Ni-Ti alloys can be plastically deformed despite rapidly cold work hardening. The flowforming process has shown promise in manufacturing these alloys but still requires further development.
### Mechanical Properties of Flowformed Titanium Alloys:

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<th>Material Description</th>
<th>Material Condition</th>
<th>.2% Yield, KSI</th>
<th>UTS, KSI</th>
<th>Elong., %</th>
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<th>Density, lbs/cu&quot;</th>
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<td>Matthew Fonte at 978-667-0202,</td>
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<td><a href="mailto:mfonte@flowform.com">mfonte@flowform.com</a>, and please</td>
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Flowformed Tubulars Made of Titanium Alloys

Matthew Fonte
Dynamic Flowform Corp.
12 Suburban Park Drive
Billerica, MA, 01821
(978)667-0202
www.flowform.com
Flowforming machine

Flowformed titanium pipe
Preforms
Definition of Flowform

An advanced, cold metal forming process used to manufacture dimensionally precise, thin wall, seamless, round, hollow components.
Flowforming Benefits

- Net-shaping forming, reduces material waste
- Economical alternative to machining bar and/or heavy wall forgings
- All flowformed pieces have:
  - Refined microstructure
  - Cold worked properties
  - Extremely uniform & concentric wall thicknesses
  - No seams or welds
- Flowformed pieces CAN have:
  - Varying wall thicknesses
  - Thin walls regardless of diameters
  - Large length to diameter ratios
Cost of Titanium Increases

Titanium 6Al-4V price based on 2.5" diameter bar at service center quoted pricing
Parts of flowforming machine

- Drive ring
- Spindle
- Headstock
- CNC Control
- 3 Rollers
- Mandrel
- 2 Ejectors
- Carriage
- Tailstock
Plastic Deformation

**Definition:** The permanent change in shape or size of a body without fracture, produced by a sustained stress beyond the elastic limit of the material.
Cold Work

Definition:
Permanently altering the shape or size of a metal by plastic deformation, carried out below the material’s recrystallization point.
Forward flowforming

Used to manufacture a cylinder with one closed or partially closed end
Forward Flowformed Components

Preform

Flowformed motor case
Reverse flowforming

Used to manufacture a cylinder with two open ends
Reverse Flowformed Components

Flowformed tube
Preform
Shearforming

Shearforming is used to manufacture conical or ogival components.
## Dimensional Control

<table>
<thead>
<tr>
<th>SIZE RANGE AND RESPECTIVE TOLERANCES OF FINISHED COMPONENTS</th>
</tr>
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<tbody>
<tr>
<td>INNER DIAMETER</td>
</tr>
<tr>
<td>WALL THICKNESS (min.)</td>
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<tr>
<td>WALL THICKNESS (max.)</td>
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<tr>
<td>MAXIMUM LENGTH</td>
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</tbody>
</table>

| INSIDE DIAMETER | ± .002" | ± .002" | ± .002" | ± .002" | ± .002" | ± .002" | ± .003" | ± .003" | ± .003" | ± .003" | ± .004" | ± .005" | ± .005" |
| WALL THICKNESS | ± .001" | ± .001" | ± .001" | ± .001" | ± .001" | ± .002" | ± .002" | ± .003" | ± .003" | ± .003" | ± .004" | ± .005" | ± .005" |
| ROUNDNESS (max.) | .002" | .002" | .003" | .002" | .003" | .003" | .003" | .003" | .004" | .004" | .006" | .008" | .010" |
| CONCENTRICITY (max.) | .001" | .001" | .001" | .001" | .001" | .002" | .002" | .002" | .002" | .002" | .002" | .002" | .003" |
| STRAIGHTNESS | .001"/ft. | .001"/ft. | .001"/ft. | .001"/ft. | .001"/ft. | .001"/ft. | .001"/ft. | .001"/ft. | .001"/ft. | .001"/ft. | .001"/ft. | .001"/ft. | .001"/ft. |
| INT. SURFACE FINISH (μinch) | 8 | 8 | 8 | 8 | 8 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| EXT. SURFACE FINISH (μinch) | 16 | 16 | 16 | 16 | 16 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |

This is a basic point of reference on tolerances. The exact tolerances are dependent on the material, size and thickness of the components as well as any post-heat treatment distortion.
Flowformed Titanums

- **Unalloyed Titaniums**
  - CP Grade 1 & 2 – pipe for CPI Industry
- **Near Alpha Titaniums**
  - Ti 6Al-2Sn-4Zr-2Mo – aircraft shaft
- **Alpha-Plus Beta Ti Alloys**
  - Ti 6Al-4V – helicopter & race car shafts
- **Near Beta Titaniums**
  - Ti 35Zr-10Nb – oxides into a ceramic
- **Beta Titanium Alloys**
  - Ti 3Al-8V-6Cr-4Zr-4Mo – rocket motor case
- **Titanium-Boron Alloys**
  - Ti 6Al-4V – developing applications
- **Shape Memory Ti Alloys**
  - Nitinol – medical & aerospace tubing
<table>
<thead>
<tr>
<th>Material</th>
<th>Specification</th>
<th>Material Condition</th>
<th>.2% Yield, KSI</th>
<th>UTS, KSI</th>
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<th>Hardness</th>
<th>Density lbs/cu&quot;</th>
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<tr>
<td>Titanium Grade 2</td>
<td>AMS 4942C</td>
<td>Annealed</td>
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<td>31</td>
<td>54</td>
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<td>As Flowformed</td>
<td>110</td>
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<td>Ti 3Al-2.5V - Grade 9</td>
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<td>72</td>
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<tr>
<td>Ti 3Al-2.5V - Grade 9</td>
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<td>Flowformed &amp; Aged</td>
<td>185</td>
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<td>Flowformed &amp; Aged</td>
<td>181</td>
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<td>157</td>
<td>26</td>
<td>40</td>
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</table>
Refined Flowformed Microstructure

Flowformed Ti 6Al-4v
Longitudinal Cross-Sectional View
Magnification: 500X

Flowformed Ti-6Al-4V
Transverse Cross-Sectional View
Grain Size ASTM No. 10 or finer
Magnification: 100X

Flowformed Ti 6Al-4V has primary globular alpha grains that have become elongated or stretched parallel to the axis, surrounded by a fine transformed beta structure, also elongated in the direction of metal flow.
Microstructural analysis – TI CP Grade 2

Flowformed

Extruded
Footprint of 3 rollers and respective metallography

A
Preform

C

B

E
Flowform

www.flowform.com
A photographic journey: Flowforming of a Titanium Seamless Pipe

8” Schedule 40

7.981” ID x .322” wall x 18 ft. long
Preforms (8” ID x 1.2” wall x 54” long)
Loading the preform onto the mandrel
Preform on the Mandrel
Start of the Flowform Process
Flowforming (1)
Flowforming (2)
Flowforming (3)
Finished flowformed pipe
Finished Titanium – Seamless pipe

Preforms
Some flowformed components
More components
Flowformed applications

- Accumulators cylinders for aircraft hydraulic systems
- Bearing sleeves
- Bicycle tubing
- Drive shafts for jet engines, helicopters and race cars
- Food and beverage cylinders
- Housings for the oil exploration industry
- Large diameter heat exchange tubing
- Nuclear waste containers
- Pipe for the petrochemical and chemical processing industry
- Pistons & cylinders for landing gear
- Pressure vessels for oxygen
- Rocket motor cases for missiles
- Rollers for the printing and packaging industries
- Satellite rocket nozzles
- Structural tubing for aircrafts and military vehicles
Dynamic’s History

- 1973 founded by Ven Fonte as Dynamic Machine Works Inc., a precision machine shop
- 1989 installed 1st flowforming machine & began flowforming
- 1996 installed large flowformer
- 2002 installed metallurgical laboratory
- 2003 increased our building from 18,000 sq. ft. to 53,000 sq. ft.
- 2004 installed 1000 ton forge press used to create preforms
- 2004 became certified to ISO 9001:2000 Quality Standards
- 2005 changed our name to Dynamic Flowform Corp.
- Today we operate six 3-roller, flowforming machines
Flowforming Department
3 Sizes of Machines
Bird’s eye view of in-house machine shop
In-house CNC machining equipment
1,000 metric ton Mechanical Forge Press

- Reduces material waste
- Vertically integrates
- Refines microstructure and improves the preform’s grain flow
Quality Assurance
In-house mechanical & metallurgical lab

- Metallography
- Tensile testing equipment
- Hardness Tester
- Magnetic particle inspection
- Dye penitrant inspection
- Hydrostatic testing
Thank you for your time and interest!

We encourage YOU to visit our facility and see flowforming first-hand, meet our team, discuss how flowforming can be applied to your next project.