

Flowformed Tubulars Made of Titanium Alloys

Written by Matthew Fonte, Dynamic Flowform Corp., September, 2006

Flowforming: Cost Savings

Titanium alloys continue to be vital for many important defense and aerospace systems. However, 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.

Economical Benefits of Flowforming

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

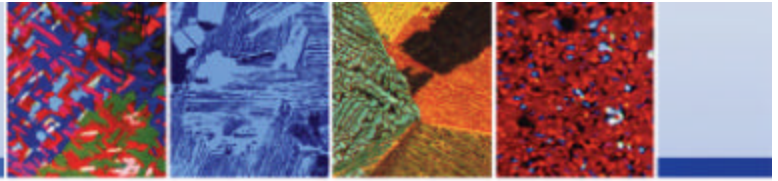
A Flowforming Machine with Titanium Pipe



On the 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.

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 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 cost savings are being offered to the Air Force for flowformed Joint Strike Fighter Titanium 6Al-4V Lift Fan™ Center Drive Shafts.



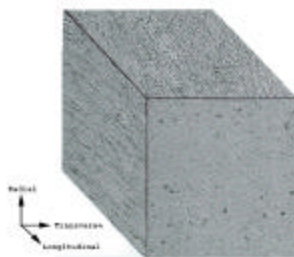
Titanium Alloy Classes

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 mechanical properties of the final part, it is necessary to review the various 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”. This critical temperature in titanium alloy processing is used to determine 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 in order to achieve the 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.

To the right 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

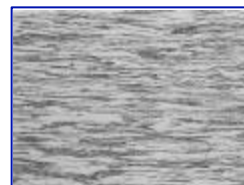


approximately 0.0001”. When the tube undergoes a post-flowform anneal, the elongated grains return to a spherical crystal structure. During annealing, the high level of stored energy in the microstructure from the flowformed cold work, expedites the recrystallization process, which produces a new grain structure without phase change. In the diagram, 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-Sn-4Zr-Mo



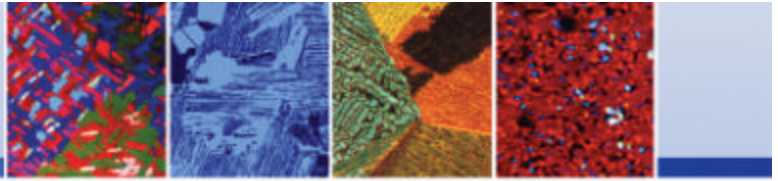
Longitudinal Cross-
Sectional View
Magnification: 500X



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 “rich” alloys include Ti-6Al-6V-2Sn and Ti-6Al-2Sn-4Zr-6Mo. The most important “lean” alloy is Ti-6Al-4V. This 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



Longitudinal Cross-Sectional View
Magnification: 500X



Transverse Cross-Sectional View showing ASTM Grain Size No. 10 or finer
Magnification: 100X

Near Beta Titanium Alloys

This family of alloys does 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 have improved formability, as compared with alpha-beta alloys; hence providing 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 CTM is an example of a commonly utilized beta alloy. Beta CTM is capable of achieving a wide range of mechanical properties. In the solution annealed condition,

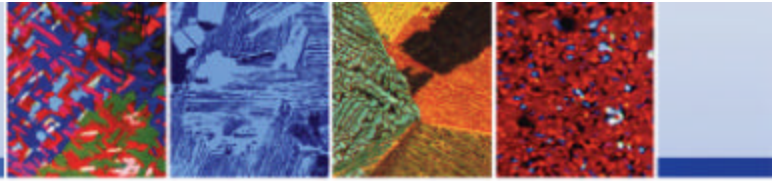
the alloy is very ductile and can be easily cold worked, unlike typical alpha-plus beta alloys. High strength levels can be developed by cold working, solution treating, and aging or a combination thereof. This alloy also exhibits very good resistance to reducing acids. The beta alloys are commonly used for aircraft springs & fasteners and as tubing in oil & gas wells. 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. This includes 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. They 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

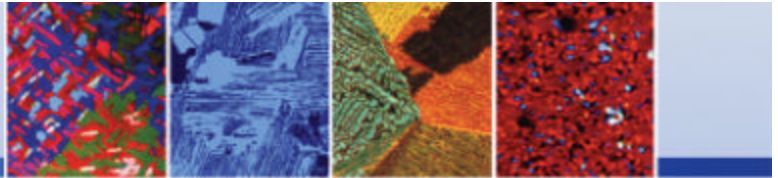
shape memory effect is induced in the wires simply by heating them with an electric current, eliminating the need for large hydraulic lines. Ni-Ti alloys can be plastically deformed despite rapid cold work hardening. The flowforming process has shown promise in manufacturing these alloys but still requires further development.

Mechanical Properties of Flowformed Titanium Alloys

Material	Specs.	Material Condition	.2% Yield, KSI	UTS, KSI	Elong. %	Hardness ~ Rc	Density lbs/cu"
Titanium Grade 2	AMS 4942C	Annealed	20	31	54	Brinell 70	1.163
Titanium Grade 2	AMS 4942C	As Flowformed	110	124	24	Rc 25	0.163
Ti 3Al-2.5V - Grade 9	AMS 4944E	Annealed	72	89	15	24	0.162
Ti 3Al-2.5V - Grade 9	AMS 4944E	As Flowformed	130	159	14	35	0.162
Ti-4Al-2.5V-1.5Fe-0.25O ₂ - ATI 425		Annealed	127	140	16	32	0.162
Ti-4Al-2.5V-1.5Fe-0.25O ₂ - ATI 425		As Flowformed	147	181	14	40	0.162
Ti-4Al-2.5V-1.5Fe-0.25O ₂ - ATI 425		Aged	175	180	11	42	0.162
Ti 6Al-2Sn-4Zr-2Mo	AMS 4975	Annealed	125	136	15	32	0.164
Ti 6Al-2Sn-4Zr-2Mo	AMS 4975	As Flowformed	158	180	13	34	0.164
Ti 6Al-2Sn-4Zr-2Mo	AMS 4976	Flowformed & Aged	140	150	15	34	0.164
Ti 6Al-4V - Grade 5	AMS 4928P	Annealed	120	130	14	36	0.162
Ti 6Al-4V - Grade 5	AMS 4928P	As Flowformed	158	193	13	41	0.162
Ti 6Al-4V - Grade 5	AMS 4928P	Flowformed & Aged	185	193	12	42	0.162
Ti 6Al-4V ELI - Grade 23	AMS 4930D	Annealed	115	125	15	25	0.162
Ti 6Al-4V ELI - Grade 23	AMS 4930D	As Flowformed	163	186	16	40	0.162
Ti 6Al-4V ELI - Grade 23	AMS 4930D	Flowformed & Aged	169	173	15	42	0.162
Ti-3Al-8V-6Cr-4Mo-4Zr - Beta C	AMS 4958	Annealed	120	125	7	32	0.174
Ti-3Al-8V-6Cr-4Mo-4Zr - Beta C	AMS 4958	As Flowformed	154	192	6	41	0.174
Ti-3Al-8V-6Cr-4Mo-4Zr - Beta C	AMS 4958	FF, Anneal & Aged	162	177	13	34	0.174
Ti-15V-3Cr-3Al-3Sn	AMS 4914A	Annealed	112	115	22	Brinell 70	0.172
Ti-15V-3Cr-3Al-3Sn	AMS 4914A	As Flowformed	189	206	6	43	0.172
Ti-15V-3Cr-3Al-3Sn	AMS 4914A	Flowformed & Aged	181	200	6	43	0.172
Ti 6Al-4V-.1B		As Cast	133	145	8	35	0.172
Ti 6Al-4V-.1B		Flowformed & Aged	181	200	6	43	0.172
Ti 6Al-4V-.1B		Flowformed & Annealed	149	157	26	40	0.172



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Conclusion:

Flowforming is a chip-less, net-shape forming process, capable of producing round, thin wall, hollow components from most Titanium alloys. Dynamic Flowform Corp. has pioneered and advanced this metal forming technology, making seamless, Titanium tubes and cylinders available to the design community. Flowformed components can be up to 24 feet long with walls as thin as 0.025". Through continuous research, Dynamic has an in-depth understanding of the effects of the flowform cold-work process on the mechanical properties of many Titanium

alloys, both with and without subsequent heat treatments. Hence, titanium and titanium alloy components can be flowformed to meet the relevant AMS and ASTM specifications as well as many application-specific mechanical property requirements, all the while reducing components' manufacturing costs. For more information, please contact Matthew Fonte at 978-667-0202, mfonte@flowform.com or please visit us on the web at www.flowform.com.