Flowforming yields dimensionally precise, round, thin-walled, seamless cylindrical components, eliminating the need for expensive secondary machining operations.

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Flowforming is a net-shape cold-forming process that enables tight dimensional accuracies on diameters and wall thicknesses, while forming extremely straight and concentric parts. Thin-walled components with large length-to-diameter ratios are perfect for flowforming, Fig. 1.

To shape the part, a cylindrical preform is fitted over a rotating mandrel. Compression is applied to the outside diameter of the preform by a set of three hydraulically driven, CNC-controlled rollers. The correct 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. Typically, the preform is rolled out to four to five times its original length, Fig. 2.

Although adiabatic heat is generated from the plastic deformation, the process is flooded with refrigerated coolant to dissipate the heat. This ensures that the material is always worked well below its recrystallization temperature. This “cold work” process causes the material’s strength and hardness properties to be increased. Additionally, dimensional accuracies are consistently achieved well beyond accuracies that could ever be realized through hot-forming processes.

Some parts that have been flowformed include accumulator cylinders for aircraft hydraulic systems, bearing sleeves, bicycle tubing, drive shafts for jet engines, housings for the oil exploration industry, nuclear waste containers, satellite rocket nozzles, and structural tubing for aircraft and military vehicles.

This article describes the economic benefits; dimensional, metallurgical, and mechanical benefits; and the results of a metallurgical evaluation.

Economic benefits
Flowforming is chipless, and is capable of forming high strength materials to net size while maintaining tight dimensional control. The technology saves money in many ways.

- Beginning with a short, thick preform and then flowforming it to greater than four times its original length (75% wall reduction) reduces material waste compared to machining.
- Flowforming is a net shape forming process, which increases material utilization and often eliminates the need for secondary operations, including machining heavy wall forgings or extrusions, and final machining, gun drilling or trepanning solid bar/billet.
- Flowforming produces seamless parts, which eliminates the cost of welding and the associated costs of testing the welds.
- Hardness levels in the mid 40s (Rockwell C scale) are realized through the combination of prehardened preforms that are subsequently cold worked from the flowforming process. This approach reduces distortion issues associated with heat treatment of a thin wall component. Furnace fixture costs and the costs associated with straightening post-heat treating distortion are eliminated.
- Flanges, stub ends, or closed bottoms can be an integral part of the flowformed component,
which eliminates the cost of manufacturing the flanges or bottoms and the cost of circumferentially welding them to the cylindrical component.

**Dimensional benefits**

The flowforming process achieves dimensional accuracies not typically found in conventional methods. The Computer Numerically Controlled (CNC) process ensures repeatable accuracies, part-to-part, lot-to-lot.

- Accurate dimensional control eliminates the need for secondary finish machining operations such as turning, grinding, and honing.
- Thin walls with varied wall thicknesses can be formed regardless of the diameter size, eliminating tool deflection associated with machining a thin wall.
- Flowformed parts are extremely round, straight, and concentric, often eliminating the need for straightening and balancing.
- Very smooth surface finishes are achieved, often eliminating the need for honing.
- Pre-hardened metals are flowformed to final size and required mechanical properties, eliminating the need to heat treat and to contend with the resulting distortion.

**Mechanical benefits**

Flowforming increases yield strength and ultimate tensile strength. Customers often choose to take advantage of the higher cold worked properties by designing thinner walls. Others prefer to have the flowformed parts stress relieved or solution annealed to remove any residual stresses in the microstructure.

These components can be heat treated or aged to alter tensile strength, hardness, and ductility. Optimum mechanical properties are often achieved by combining flowformed cold work and subsequent stress relieving and/or direct aging. In some instances, certain alloys can be hardened only through cold work, and flowforming is a very sound and repeatable method of doing so.

Another mechanical benefit is that the products are seamless. This eliminates problems associated with welding, such as heat-affected zones, porosity issues, potential inclusions, and potential weld failure.

Flowformed parts are often superior to welded products in terms of their concentricity and roundness. This contributes to overall cost savings by eliminating potential welding manufacturing problems and the operations associated with creating and testing the welds.

**Metallurgical benefits**

During flowforming, the preform material is plastically deformed, and wall thickness is greatly reduced, usually by 75 to 80%. Cold work refines the preform grain structure and realigns the microstructure in a very uniform, longitudinal and axial direction. If preferred, the flowformed grain structure can be recrystallized with a post-flowform anneal. This can be a stress relieve or a full solution anneal that rids the component of its cold work stresses.
The grain structure samples were extruded. The crystallographic flow form. The overall texture of the flowformed material had radially oriented planes, and this provides higher biaxial strength, in both the longitudinal and transverse orientations. To evaluate this effect, Massachusetts Materials Research Inc. of West Boylston, Mass., and Lambda Research of Cincinnati, Ohio, were commissioned to test tubing material that was processed two ways: cold-worked flowforming and hot-worked extruding. Titanium Commercially Pure Grade 2 (Ti CP2) was chosen as the material, as it is a commonly flowformed metal.

Metallurgical evaluation
Within the grain structure of metals, crystals are moved and aligned during cold working. The overall orientation of the crystals is known as the texture. The overall texture of flowformed material has radially oriented planes, and this provides higher biaxial strength, in both the longitudinal and transverse orientations.

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Microstructure: The grain structure samples were documented through preparation of metallographic cross sections in three orientations:
- Longitudinal (parallel to the length of the tube)
- Transverse (across the width of the tube)
- Radial (flat-wise on the surface of the tube)

The microstructures were then documented by photographing the etched cross sections at 500X magnification. The microphotographs in each orientation were combined to create a simulated three-dimensional view of the grain structure in the three orientations. The microstructure (grain structure) of the flowformed material is shown in Fig. 3. The microstructure of the as-extruded material is shown in Fig. 4.

The microstructure of the flowformed material is significantly altered compared to the as-extruded material. With flowforming, the grains are elongated and flattened to create an “elongated pancake” shape. The grain size in the transverse orientation is very fine, with average grain size of 2.5 microns or ASTM no. 14. The microstructure of the as-extruded material is equiaxed and is significantly larger, measuring an approximate average grain size of 9.5 microns or ASTM No. 9.

Crystallographic Texture: The crystallographic texture was determined by X-ray diffraction techniques. This involves conducting pole figure measurements in conjunction with Orientation Distribution Function (ODF) analysis to define the preferred crystallographic orientations of the flowformed sample versus the as-extruded sample.

However, the microstructure remains refined even after a recrystallization heat treatment. Typically, the greater the wall reduction, the finer the grain microstructure and the less susceptible the material is to stress-corrosion cracking, especially after a post-flowform heat treatment.

The texture revealed by the inverse pole figures, shown in Fig. 5, indicates basal <001> orientation evident in the normal, or radial, direction for the flowformed sample.

The flowformed specimen had <-1 -1.0> and <-21.0> texture in the longitudinal direction. The as-extruded microstructure, shown in Fig. 6, indicates a random or weak texture with some intensity depicted in the longitudinal direction. The as-extruded specimen exhibited primarily <0 -1.0> and <10.0> texture in the longitudinal direction.

To assess the texture of radially oriented basal planes, a scale of 0 to 6 is used with 6 “random” being the most textured. Note that the intensity of the “as flowformed texture” in Fig. 5 is between 5 and 6 random, which is a highly textured “preferred orientation.”

The “as extruded texture” in Fig. 6 is between 1 and 2 random, a very weak or non-existent texture. This non-existent texture can be attributed to the fact that the material was “hot work” extruded above the material’s transus temperature, and no dynamic recrystallization occurred.

The results of the crystallographic texture analysis revealed very significant differences between the two methods of processing the titanium. The overall texture of the flowformed material had radially oriented basal planes of the hexagonal close-packed (HCP) crystal structure. The radial texture provides an increased biaxial strength, in both the longitudinal and transverse orientations. Since mechanical properties are influenced and strengthened by texture, the flowformed oriented texture results in a stronger component.

Flowformed material and sizes
Many different materials can be flowformed utilizing the same equipment, tooling, and setups. Advanced materials ranging from high strength aluminum to doped zirconium, which are often solely available in bar or billet, are successfully flowformed into precision tubular parts. Seamless components that have length-to-diameter ratios such as 4 to 1 and as high as 20 to 1 often realize the greatest cost savings. Design engineers, metallurgists, and procurement groups who always appreciated the dimensional, mechanical, and metallurgical benefits of this manufacturing process are now strategically taking advantage of the economics of flowforming.

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