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[54] **MANUFACTURE OF TUBES WITH IMPROVED METALLIC YIELD STRENGTH AND ELONGATION PROPERTIES**


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[58] **Field of Search** ..... 148/11.5; 72/302, 378, 72/392, 255, 367



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[57] **ABSTRACT**

A process for the manufacture of metal tubes, wherein the tubes exhibit improved yield strength, axial elongation and circumferential elongation properties. The tube is initially cold worked to obtain final size, which develops a certain strength to the metal of the tube and produces uniformity in the dimensions of the tube. A subsequent annealing increases the ductility of the metal in the tube. After annealing the tube is stretched significantly with the simultaneous reduction of the diameter thereof, to obtain a final product where the wall of the tube has been work hardened by such stretching. The latter operation increases the yield strength in the tube wall without failure occurring. A process of the type indicated where the annealing is a recrystallizing annealing, effective to produce recrystallizing of the microstructure of the tube's metal, and wherein the stretching is done without internal or external support of the tube wall.


**7 Claims, No Drawings**

# MANUFACTURE OF TUBES WITH IMPROVED METALLIC YIELD STRENGTH AND ELONGATION PROPERTIES

This invention relates to a tube manufacturing process, and more particularly to a process of manufacturing a tube from tubular stock having a relatively high yield strength, together with excellent circumferential elongation, and axial elongation properties.

In the manufacture of tubing, it has been conventional practice to process a tube having a relatively large tube wall area by cold working the tube, to produce a reduction in this tube wall area (by reducing the wall thickness and/or by reducing the tube diameter). Thus, a tubular product, such as what is known as a tube hollow or an intermediate, may be cold worked as by passing the same through a tube reducer, swaging apparatus, or a drawing process to effect a reduction in tube wall area. The cold working results in a tube which is uniformly dimensioned. The cold working also has the effect of increasing the yield strength of the metal in the tube, which may be defined herein as the force per unit area or stress applied to a tube specimen necessary to produce a marked and permanent deformation in the specimen.

While a high yield strength is a desirable property, another result accompanying the cold working described is a substantial decrease in the ductility of the metal making up the tube. This decrease in ductility is evidenced in relatively low axial elongation and circumferential elongation properties. These latter properties, as will be brought out, relate to the amount of elongation that the wall of the tube will undergo when subjecting the tube to stressing sufficient to produce failure. The specifications prescribed for tubing will vary depending upon the particular requirements of a user, but generally speaking it is desirable to have not only a high yield strength, but at the same time high circumferential and axial elongation properties.

In an attempt to improve the elongation properties of tubing after cold working, various treatments have been resorted to, including the step of stress relief annealing the tubing, which might generally be described as an annealing performed to eliminate stress only and without producing recrystallization of the microstructure of the metal of the tube. Such an annealing improves ductility and elongation properties, but in many instances the improvement is sufficient only barely to raise the properties of the tube specimen above specification minimums.

Generally, therefore, an object of this invention is to provide a novel process for making tubing with the metal of the tubing possessing a relatively high yield strength, where the tubing also exhibits high circumferential and axial elongation properties.

Another object is to provide a process for making tubing which relies upon a stretching of an annealed tube to produce improved yield strength properties, the metal of the tubing at the same time having the ductility to impart suprisingly good elongation characteristics to the tubing.

In one embodiment of the invention, the tubing after cold working is subjected to a recrystallizing or full annealing step at elevated temperatures. The annealing recrystallizes the microstructure of the metal of the tube, to produce equiaxed grains therein. Without further processing, this results in a product exhibiting exceptionally good elongation figures but relatively low yield strength. When such is subsequently stretched significantly with the simultaneous reduction of the diameter of the tube, the yield strength may be raised to a significantly higher figure without substantial reduction in the elongation characteristics of the tube. Stretching may be done without internal or external support of the wall of the tube, with the tube diameter reducing uniformly along the length of the tube.



In another embodiment of the invention, tubing after being cold worked is subjected to a stress-relief annealing, and subsequently stretched under conditions wherein the wall of the tube is supported, to produce a final tube having a combination of superior yield strength and elongation properties.

These and other objects and advantages are attained by the invention, which will be described hereinbelow in conjunction with certain examples set forth fully to illustrate the invention.

Tubes of titanium, zirconium and their alloys, for example, because of chemical and physical properties they possess, have a number of specialized uses frequently requiring the tubes to meet exacting specifications to be acceptable for such uses. A difficulty that has been experienced is that while a certain manufacturing process may be utilized in making a tube to improve one of its properties, this treatment may so adversely effect other properties in the tube that the tube fails to meet required specifications. As contemplated by this invention, tubes may be produced exhibiting a combination of superior yield strength and elongation properties, heretofore not realized using known procedures.

Describing embodiments of the invention in further detail, zirconium alloy tubes such as Zircaloy tubes presently are employed as fuel cladding in nuclear reactors. Commonly, tubes for this purpose may have an outer diameter ranging from about 0.4 to 0.6 inch, and a wall thickness within the range of about 0.015 to 0.035 inch. The necessity for reliable performance in tubes put to this use has resulted in those responsible for constructing reactors in drafting specifications for the tubes calling for a combination of relatively high yield strength, axial elongation and circumferential elongation properties. Thus, and by way of illustration, a specification might require a yield strength of 28,000 p.s.i. at a 750° F. test temperature, an axial elongation at room temperature (expressed as percent) of 18 percent, and a circumferential elongation at room temperature (expressed as percent) of 12 percent. The figures just set forth, of course, are exemplary only of what a particular reactor installation might require, and are subject to variation.

In preparing a tube to meet the above specification, and using existing techniques, a manufacturer might pass a tube hollow or intermediate through a so-called tube reducer, exemplified by the well known cold pilger mill including rockable dies that squeeze the tube wall over an internal supporting mandrel, effective to produce a reduction in the tube wall area of the hollow and to form a tube of the finally desired uniform dimensions. Alternatively, and as already indicated, the hollow might be cold worked as by a swaging operation, or by drawing the tube. With this type of treatment, a hollow having an outer diameter of 2.5 inches and a wall thickness of 0.400 inch might be reduced in size to a tube having an outer diameter of approxi-

mately ½ inch, and a wall thickness of, for example, 0.020 inch. The cold working is effective to impart substantial yield strength to the metal of the tube which, for instance, might approximate 80,000 p.s.i. as tested at, for example 750° F. However, such cold working detracts from the ductility of the metal, which is reflected in relatively low axial and circumferential elongation figures, which would prevent such tube from meeeting the above-indicated specifications.

Further describing conventional practice, to improve elongation properties the tube might be subjected to a stressrelief annealing, carried out without recrystallization of the microstructure. Such an annealing is effective to increase the axial and circumferential elongation properties exhibited by the tube. The improvement, however, may be relatively slight. When variation between tested specimens is also taken into account analytically, using what is referred to as a standard deviation, the improvement may not be sufficient to permit acceptance of the tube for reactor purposes.

In discussing yield strength, the determination is made at an elevated temperature, i.e., 750° F. The yield strength referred to herein is the 0.2 percent offset strength exhibited by the tube, determined using recognized ASTM procedures (E8-69 entitled Standard Methods of Tension Testing of Metallic Materials).

In discussing elongation figures herein, such determinations are made at room temperature. Considering percent axial elongation, a standard gauge length measuring 2 inches in length is used. The specimen is placed in a tensile testing machine, and stretched until broken. The composite length of the pieces is then determined, and the excess of such length over the original 2 inch length is expressed as a percent of the original length.

Considering circumferential elongation, such may be determined by hydrostatically pressurizing the interior of a tube until the same bursts. The outer circumference of the tube at the location of the burst is measured from "lip to lip" or from one edge of the burst location to the edge opposite. The difference of this measurement and the original circumference of the tube is then expressed as a percent of the original circumference, to obtain circumferential elongation.

Describing an embodiment of the invention, a tube as represented by a tube hollow or intermediate, may be cold worked to reduce the tube wall area and to produce a tube of uniform dimensions having reduced outer diameter and wall thickness. The resultant tube may then be subjected to a full annealing or recrystallizing annealing, which is an annealing, carried on at an elevated temperature, effective to produce recrystallization in the metallic microstructure, and with the formation of equiaxed grains. With the usual Zircaloy tube, for instance, this recrystallizing annealing may take place at a temperature of about 1,350° F., over a period of 30 minutes to four hours, depending upon the loading of the chamber in which the annealing takes place. The completion of the annealing process is determined by inspection of the microcrystalline structure of the metal in the tube. At the completion of this recrystallizing annealing, the metal of the tube is quite ductile, which is reflected in a relatively low yield strength. However, the axial and circumferential elongation properties of the tube are relatively high, and well above the indicated values set forth above for a typical specification above.

At the completion of the annealing, the tube is stretched to effect a significant reduction in the outer diameter of the tube. The stretching may be done in a free drawing process, i.e., without external or internal support of the tube wall. The stretching generally can be characterized as producing from 0.75 to a 6 percent reduction in the outer diameter of the tube, preferably a reduction lying within the range of 1.5 to 5 percent. This reduction in diameter is significantly greater than any reduction that might occur in a straightening process, for instance, wherein the maximum diameter reduction might not exceed 0.2 percent. As the tube is stretched, and during the initial stretching, certain portions of the tube wall along the tube's length will elongate in preference to other portions, with these first-to-elongate portions then work hardening to restrict elongation. The remaining portions of the tube will then to elongate with subsequent work hardening. The tube in its final state is work hardened throughout its entire length, and has a substantially uniform diameter and wall thickness throughout. In a tube, for instance, which before stretching shows a variation in outer diameter not exceeding 0.003 inch, and a variation in wall thickness not exceeding the same amount, using the method of the invention the variation in outer diameter and wall thickness after stretching will be within the range indicated.

The metal of the tube, after the stretching indicated, and through the work hardening which occurs throughout its entire length, possesses a substantially greater yield strength than it did at the completion of the recrystallizing annealing step. However, at the same time the ductility of the metal in the tube is not overly effected, so that axial and circumferential elongation figures obtained on the final tube are only slightly less than those obtained before the stretching process.

By way of example, a Zircaloy tube hollow having an outer diameter of 2.5 inches and a wall thickness of 0.400 inch was reduced with four passes through a Mannesmann-McKay tube reducer, to obtain a 0.430 O.D. tube having a wall thickness of 0.048 inch. The tube was made of Zircaloy 4, containing in addition to zirconium (by weight), 1.5 percent tin, 0.2 percent iron, and 0.20 percent chromium. In the final tube, the variation in outer diameter along the length of the tube did not exceed 0.002 inch, and the variation in wall thickness did not exceed 0.002 inch. The tube so prepared was fully annealed at a temperature of 1,350° F. (a temperature below the beta transis temperature of the alloy to inhibit change in allotropic form) until micrographic analysis of the microstructure in the tube demonstrated that recrystallization was complete with the formation of equiaxed grains.

The yield strength of the metal in the tube after the full annealing was approximately 18,000 p.s.i. at 750° F. Axial elongation was determined to be 28 percent and circumferential elongation 26 percent, both at room temperature.

The tube was then stretched using free drawing to obtain a permanent reduction in the diameter of the tube of 0.010 inch. The outer diameter of the final tube was substantially uniform throughout, showing a variation not exceeding 0.002 inch.

Such a tube was then tested to determine yield strength, and axial and circumferential elongation

properties. The yield strength of the tube at 750° F. was 31,000 p.s.i. Axial elongation at room temperature was 26 percent and circumferential elongation at room temperature was 24 percent. It will be noted that the yield strength of the tube was substantially increased without significant change in the elongation figures. It will be further noted that with a specification calling for 28,000 p.s.i. yield strength, 18 percent axial elongation, and 12 percent circumferential elongation, a tube as so produced has properties well exceeding such minimum values.

According to this invention, it is further possible to prepare tubes with improved characteristics and exhibiting greater yield strength at the expense of slightly lesser elongation values, where the annealing that is performed is a stress-relief annealing, and where the tube wall is supported during the stretching process to achieve uniformity in tube wall diameter after the stretching has been performed. The support for the tube wall is required when a stress-relief annealing is performed, since it has been found that with this type of annealing only with support are final uniform dimensions achieved.

By way of an example, another tube hollow of the type described in the first-mentioned example, was processed in a tube reducer to obtain a cold worked tube of reduced diameter and wall thickness having the yield strength and elongation properties above-indicated for the first set forth example. Such tube was then stress-relief annealed, at a temperature of 970° F. for approximately 1 hour or until free of internal stresses.

After the stress-relief annealing, the metal of the tube exhibited a yield strength of 34,000 p.s.i. Testing for axial elongation yielded a figure of 24 percent and circumferential elongation a figure of 18 percent.

The tube was stretched to reduce the outer diameter 0.010 inch, with pulling of the tube through a die having a diameter of 0.420 inch, i.e., a diameter 0.010 inch less than the outer diameter of the tube being stretched. In this way, during the stretching process, the outer diameter of the tube was supported. The metal of the tube so stretched exhibited a yield strength of 48,000 p.s.i. Axial elongation and circumferential elongation for the tube, in terms of percent, were found to be 19 percent and 15 percent, respectively. It will be noted from the above that the stretching produced significant increase in the demonstrated yield strength without appreciable reduction in the elongation figures.

It will be noted from the above that the stretching contemplated offers a relatively convenient means for introducing substantial improvement in yield strength to a tube specimen without appreciably detracting from the circumferential axial elongation properties. Through the expedient of fully or recrystallizing annealing the tube after the cold working, a product is formed which can be stretched without wall support to obtain a uniformly dimensioned tube having a yield strength significantly greater than possessed prior to the stretching, in conjunction with axial and circumferential elongation properties formerly not obtainable using prior art techniques.

While different embodiments and modifications of the invention have been described, it is appreciated that variations are possible without departing from the invention.

It is claimed and desired to secure by Letters Patent:

**1.** A process for the manufacture of a metal tube comprising
- cold working a tube to reduce the tube wall area thereof and by such cold working increasing the yield strength in the metal of the tube and obtaining a uniformly dimensioned tube,
- after such cold working annealing the tube by heating the tube at an elevated temperature and then cooling the tube, to increase the ductility of the metal in the tube and to obtain improved axial and circumferential elongation properties, and
- with the tube in the state that results from the annealing subsequently stretching the tube, to obtain a reduction in the outer diameter thereof ranging from 0.75 to 6 percent, to obtain a resultant tube where the metal of the tube has been work hardened by the stretching, the resultant tube having yield strength properties which are substantially increased by said stretching.

**2.** The process of claim **1,** wherein the annealing is a recrystallizing annealing, effective to produce recrystallizing of the microstructure of the metal in the tube, with the formation of equiaxed grains in said microstructure.

**3.** The process of claim **2,** wherein the stretching is performed without external and internal support of the wall of the tube.

**4.** The process of claim **1,** wherein the annealing is a stress-relief annealing carried out without recrystallizing of the microstructure of the metal in the tube, and stretching is performed with support of the wall of the tube during stretching.

**5.** A method of manufacturing a metal tube exhibiting improved yield strength, axial elongation and circumferential elongation properties comprising
- cold working the tube to produce a reduction in the tube wall area of the tube,
- recrystallizing annealing the tube after such cold working by heating the tube at an elevated temperature and then cooling the tube, with such being effective to produce recrystallizing of the microstructure of the tube's metal with the formation of equiaxed grains in said microstructure, and
- stretching the tube in the state that it has after such annealing to reduce the outer diameter thereof and to obtain a final product where the wall of the tube has been work hardened by such stretching.

**6.** The method of claim **5,** wherein the cold working of the tube is performed by passing the tube through a tube reducer with working of the metal of the tube against an internal mandrel.

**7.** A method of manufacturing a metal tube exhibiting improved yield strength, axial elongation and circumferential elongation properties comprising
- cold working the tube to produce a reduction in the tube wall area of the tube,
- stress-relief annealing the tube after such cold working by heating and then cooling the tube, without recrystallizing the microstructure of the tube's metal, and by such annealing increasing the ductility of the metal in the tube, thus to obtain improved axial and circumferential elongation properties, and
- subsequent to such annealing and with the tube in the state that results from the annealing, stretching the tube to obtain a reduction in the outer diameter thereof, with such stretching being effective to work harden the metal of the tube thereby to increase the yield strength, said stretching being performed with support of the tube wall during the stretching process.

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