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METHOD FOR STRENGTHENING IRON BASE ALLOYS

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This invention relates to a method for imparting strength to iron base alloys by deforming them through inducing primarily tensile stresses in them at sub-zero temperatures.

At the present time, difficulties have been encountered in producing articles such as thin walled pressure vessels which have high strength and yet are precisely dimensioned. The term "thin walled" as used in the pressure vessel industry refers to a vessel whose wall thickness to diameter ration is sufficiently small to give primarily tensile stresses in the wall when the vessel is subjected to internal pressures. The compressive stresses induced in the walls of the thin walled pressure vessels when subjected to internal pressures are insignificant. These articles, which employ welded seals, must frequently be quench hardened after fabrication. The quench hardening increases the strength of the article but at the same time frequently results in its distortion. Also, when the particular article is quite large in size, it is difficult to accommodate in conventional quench hardening facilities.

An object of the present invention is to provide a method which produces increased strength in articles made from iron base alloys and at the same time produces closely dimensioned articles. A further object of the invention is to provide a method for imparting strength to an annealed austenitic stainless steel by cooling the steel to a sub-zero temperature (from about −50 to about −400° F.) which temperature is in the region of the normal martensitic transformation temperature (M_s) of the stainless steel, and primarily imparting tensile stress to the stainless steel at the sub-zero (°F.) temperature to produce controlled permanent set up to about fifteen percent of the original dimension of the stainless steel article.

Still another object of this invention is to provide a method for imparting increased strength to a thin walled pressure vessel composed of an annealed austenitic stainless steel by applying to the pressure vessel a sub-zero liquid having a temperature in the order of the normal martensitic transformation temperature of the stainless steel and then pressurizing the pressure vessel to produce in it a permanent set up to about fifteen percent of its original dimensions.

My invention is accomplished by deforming an annealed austenitic stainless steel at a subzero temperature in the order of the normal martensitic transformation temperature of the stainless steel. Preferably, the subzero temperature employed is equal to or slightly less (in the order of 50° F. less) than the normal martensitic transformation temperature at which the annealed austenitic stainless steel transforms to martensite.

By normal martensitic transformation temperature, I mean that temperature at which the alloy begins to transform from austenite to martensite solely as a result of rapid cooling. This is to be distinguished from the actual martensitic transformation temperature which will in my process be higher than the normal martensitic transformation temperature. This results from the fact that the metal, when strained, begins to transform from austenite to martensite at a temperature above the normal martensitic transformation temperature. Thus, the effect of straining the metal is to increase the martensitic transformation temperature.

In deforming the annealed austenitic stainless steel at a subzero temperature, I place it primarily in tension and achieve the desired result of greatly improving the strength of the article while at the same time retaining reasonable ductility.

By the term "austenitic stainless steels" I refer generally to iron base alloys containing from about sixteen to about twenty-six percent by weight of chromium, from six to about twenty-two percent by weight of nickel, and in addition minor amounts of other elements such as carbon, manganese, silicon, molybdenum and phosphorous.

To further illustrate this invention, there are presented the following examples in which all parts and percentages are by weight. These examples are presented only for the purpose of illustrating the invention and should not be construed as limiting the scope of the invention in any way.

Example I

An austenitic stainless steel alloy having an AISI–301 designation and containing from sixteen to eighteen percent chromium, from six to eight percent nickel, a maximum carbon content of 0.15 percent, a maximum manganese content of 2.00 percent and a maximum silicon content of 1.00 percent, with the balance being iron, was cooled to about −320° F. by contacting it with liquid nitrogen. The metal was then placed in tension and stretched until the cross-sectional area of the specimen had been reduced 13 percent from the original cross-sectional area. As a result of this treatment the strength of the metal was greatly increased. On specimens from two such runs tests at room temperature showed yield strengths at 0.2 percent offset of 200,000 lb./in.^{2} and 190,500 lb./in.^{2} respectively, ultimate tensile strengths of 256,000 lb./in.^{2} and 268,000 lb./in.^{2} respectively and hardnesses of 51.5 and 53 Rockwell C units respectively. On subjecting a hardened specimen to aging for twenty-four hours at 550° F., it was found that the mechanical properties were further enhanced. On testing at room temperature the yield strength of the aged specimen at 0.2 percent offset was 269,000 lb./in.^{2}, the ultimate tensile strength was 274,000 lb./in.^{2}, and the Rockwell C hardness was 53.

The properties for the 301 stainless steel in the annealed condition (prior to treatment as in Example 1) are 35,000 lb./in.^{2} minimum yield strength and 100,000 lb./in.^{2} minimum ultimate strength.

Example II

When Example I is repeated using the respective alloys set forth in the following table, in each case the mechanical properties of the alloy are greatly improved to give increased strength while maintaining reasonable ductility.

Alloy	Percent Fe	Percent Cr	Percent Ni	Percent C, maximum	Percent Mn, maximum	Percent Si, maximum	Percent Mo	Percent Cb
A	Balance	18	9	0.15	2.00	1.00	------	------
B	do	19	10	0.08	2.00	1.00	------	------
C	do	17	12	0.08	2.00	1.00	2.5	------
D	do	19	13	0.08	2.00	1.00	3.5	------
E	do	18	10.5	0.08	2.00	1.00	------	0.8
F	do	25	20.5	0.25	2.00	1.50	------	------

As illustrated above, my method works very well in greatly improving the strength of annealed austenitic stainless steels. Preferably, the amount of permanent set introduced by tensile loading of the metal article ranges between about ten to about fifteen percent. Even more preferably, it has been found that a range of permanent set from about ten to about thirteen percent produces optimum results.

Any suitable cooling medium can be employed in cooling the metal article to the subzero temperature at which it is to be deformed. A preferred cooling medium is liquid nitrogen since it is relatively economical and safe to work with. Other cooling media may be employed, however, and include such diverse media as liquid helium, and organic liquids.

An advantage of my method resides in the fact that it can be employed for treating an article after it has been fabricated. By treating the article in its fabricated form, the welded portions of the article are treated along with the remainder of the metal in the article. This produces relatively uniform strength throughout the entire article including the welds. This represents a great advantage over conventional processes in which the welding together of two previously heat treated metal parts can result in radically altering the characteristics of the metal in or adjacent to the weld. These radical alterations result from the fact that the heat of welding produces undesirable changes in the previously heat treated metal parts. Also, my process results in working the metal in the region of the welds which changes the cast structure of the metal in the weld and reduces its grain size to give increased strength. Further, since my method produces uniform strength throughout the fabricated article, it is not necessary to use thick welds as employed in the past to provide a large quantity of metal in the area of the weld to act as a safety factor in view of nonuniform metal characteristics in and adjacent to the weld. The use of thick welds, as required in prior art processes, produced undesirable results since the sharp change in thickness at the region of the weld resulted in stress concentrations at that region when the metal part was subject to loading. Since my method minimizes the need for thick welds, it enables the production of metal articles which do not require abrupt changes in thickness with the accompanying stress concentration at these points.

Following the hardening of the annealed austenitic stainless steel according to my method, it is frequently desirable to subject the hardened article to aging. This involves maintaining the metal article at a temperature within the range of from about 500° F. to about 900° F. for a period up to about forty-eight hours. The aging step is not essential but does act to relieve lattice distortion in the metal and provide improved properties in the finished product.

A preferred application of my method is in the subzero hardening of pressure vessels. In this particular application, the pressure vessel composed of an austenitic stainless steel, as defined previously, is internally pressurized with a liquid at subzero temperatures such as liquid nitrogen which has a temperature in the order of −320° F. The pressure created within the pressure vessel by the subzero liquid is sufficient to deform the pressure vessel and provide from about ten to about fifteen percent permanent set. When this operation is completed the subzero liquid is removed from the interior of the pressure vessel and the vessel can then, if desired, be subjected to aging as defined previously.

A convenient way of employing my method involves placing the pressure vessel to be hardened within a large mold whose interior surfaces define a cavity which is slightly larger than the exterior dimensions of the finished pressure vessel. When the pressure vessel is then internally pressurized with a subzero liquid such as liquid nitrogen, the pressure vessel is deformed in a controlled manner and its wall thickness is reduced uniformly until the vessel comes in contact with the interior surfaces of the surrounding mold. One way of measuring the degree of deformation of the vessel is to observe the decrease in thickness of the walls of the vessel. Thus, when the vessel has had a permanent set of fifteen percent, the wall thickness of the vessel will have been reduced by about fifteen percent. The amount of permanent set can readily be determined by strain gages placed on the outside of the pressure vessel. The pressure vessel can first be pressurized with the subzero liquid at a pressure sufficient to produce a stress equivalent to the proportional limit of the annealed stainless steel. This pressurization step is to check the vessel to assure that it has no leaks. The vessel can then be repressurized with the subzero fluid to give the vessel a permanent set up to about fifteen percent. In same cases, a pressure of an amount sufficient to give a stress equivalent to ten percent in excess of the proportional limit of the annealed stainless steel is sufficient to produce the desired permanent set in the vessel.

The vessel can be given the desired permanent set in one pressure application. Conversely, the permanent set can be obtained in a stepwise operation by pressurizing with the subzero liquid and obtaining a given permanent set, evacuating the liquid, repressuring to give a further permanet set, etc. In this manner the rate of deforming the vessel in a controlled manner can be carefully controlled. Also, the rate of deforming can be controlled in one pressurization operation by applying a greater or lesser pressure within the vessel to obtain a faster or slower rate of controlled deformation. When the operation is completed the subzero fluid is removed from the pressure vessel, the mold is opened, and the treated pressure vessel is removed from the mold.

An ancillary advantage of both cooling and giving a permanent set to the pressure vessel through the application of a subzero liquid to its interior resides in the fact that the hardening operation also serves to detect any flaws or leaks in the pressure vessel. If there are flaws or leaks in the pressure vessel, the pressure vessel will rupture or leak at the point of occurrence of the flaw or leak.

Having fully defined my novel invention and its application to the production of metal objects having superior strength, I desire to be limited only within the lawful scope of the appended claims.

I claim:

1. Method for hardening and strengthening a pressure vessel composed of an annealed austenitic stainless steel which method comprises introducing within said pressure vessel a subzero liquid whereby said pressure vessel is cooled to a temperature in the order of the martensitic transformation temperature for the stainless steel comprising said pressure vessel, and thereafter deforming said pressure vessel in an amount up to about fifteen percent deformation through means of the pressure applied to the interior of said pressure vessel by the subzero fluid.

2. The process of claim **1** wherein said subzero fluid is liquid nitrogen.

3. The process of claim **1** wherein said pressure vessel is surrounded by a mold whose dimensions are slightly larger than the outside dimensions of said pressure vessel so that on deformation of said pressure vessel it is forced into contact with the walls of said mold.

4. The method of claim **1** wherein the amount of deformation ranges between about ten to about fifteen percent.

5. The method of claim **4** wherein the degree of deformation ranges between about ten to about thirteen percent deformation.

6. The method of claim **1** wherein the hardened stainless steel alloy is then heated to a temperature between about 500° F. to about 900° F. for a period up to about forty-eight hours.

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