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CRYOGENIC QUENCHING METHOD

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This invention relates to a quenching method for metal parts undergoing heat treatment, and, in particular, to a method of treating aluminum alloy and other metallic parts for improving the physical properties thereof.

Although tests have shown that my method can be used for quenching other metals and alloys, I have found that it is particularly valuable in the heat treatment of the aluminum alloys used extensively for structural parts of aircraft. However, although in the following discussion of the salient features of my invention I will refer generally to the practice of my invention in connecton with aluminum alloys as used in the aircraft industry, I do not intend to limit my invention thereto.

In the manufacture of aluminum alloy aircraft components, the parts formed by stamping, pressing, bending, and other manufacturing operations should be worked in the soft condition to avoid fractures or spring-back. Because of the low strength and, to a lesser extent, the inferior corrosion resistance of the aluminum alloy in the soft condition, parts tin this condition are unsuited for the high-strength requirements of modern usage. It is the usual practice, therefore, to subject the parts after being worked in the soft condition, to various treatments to obtain the required physical properties. For aluminum alloys, it is necessary to produce the optimum percentage of alloying element in solid solution such that the desired physical properties are imparted to the parts. Conventionally, such treatment normally consists of heating the part to a predetermined temperature, maintaining the part at that temperature for a specified length of time, and thereafter cooling or quenching the part. Quenching is ordinarily accomplished by plunging the part into cold water. Such quenching is effective in rapidly cooling the part and thus producing the required physical properties, but the stresses locked into the metal by such quenching almost invariably cause a serious warping of the part or excessive residual stresses in massive parts that do not warp. The presence of such locked-in-stresses is regarded as undesirable, as they often reduce the strength of the part. It has also been found that in heavier parts, while warping may be insignificant after quenching, any subsequent machining of the part causes a redistribution of the locked-in stresses that can result in serious warping. It should be emphasized that these locked-in or residual stresses are not to be confused with the strains set up when a part is cold-worked as such cold working produces stresses which result in an increase in the hardness and strength of the part. Broadly speaking, any stresses that cause warpage in a part when a portion thereof has been removed, as by machining, are regarded as constituting undesirable locked-in stresses.

Various means such as a less drastic quenching or a mechanical treatment have been proposed for reducing these stresses. Other approaches for reducing locked-in stresses in heat treated aluminum have included the employment of such quenching media as boiling water or hot oil. However, it has not been possible to attain the required metallurgical properties of the part with these quenches. The same objection obtains in the prior art method in which the part is quenched in a fog-like atmosphere produced by spraying water into a moving body of air. Although this prior art method is claimed to produce a substantially distortion-free part, it has not found

wide application because of the resultant unfavorable metallurgical properties.

Because of this lack of success with conventional quenching methods to produce distortion-free parts with the required physical properties, it has been the practice, therefore, to use a cold-water quench to attain the required properties and to straighten stress-warped parts immediately after the quenching operation and before the metal has hardened to the extent that it becomes unworkable. In the past, this period in which it was possible to work a part was restricted by short time limits. Even though it is currently the practice to refrigerate parts to arrest or retard the hardening process, there still is a time limitation involved, and in addition, the refrigerators themselves represent a not inconsiderable expenditure in money and space.

It is thus the principal object of my invention to provide an improved quenching method that is not subject to the limitations of the prior art methods and in which the required metallurgical properties are obtained in articles without the accompanying development of residual stresses which produce warping and distortion.

Yet another object of my invention is the provision of an improved quenching method in which the freedom from the usual metal distortion of the quenching operation will permit complex and difficult to form parts to be formed in the softened condition and subsequently heat treated to obtain the required physical properties in the metal.

A further object of my invention is to provide an improved quenching method which produces changes in the metal necessary to improve the physical properties and corrosion resistance thereof without causing such warpage as will require subsequent straightening. Metal parts produced according to my invention are suitable for use without further working, thus shortening the process and time of production, and permitting a reduction in cost to be effected by eliminating the manpower, equipment, and floor space required for hand hammering and straightening. In addition, objects of uniform shape, size, and characteristics may be produced on a high-volume basis that is conducive to a high degree of automation.

It is yet another object of my invention to provide an improved quenching method that is not restricted to one specific type or group of metals or alloys. When used with steels, for example, more complete hardening as well as a reduction in the amount of detrimental constituents that effect ductility and corrosion resistance are attainable and, in addition, because less retained austenite is produced, an elimination of the "cold stabilizing" process for steels is feasible.

These and other objects and advantages of the method of my invention are attained by directly quenching the part upon removal from the means in or by which it has been solution heat treated, into a cryogenic medium such as a liquefied gas or the vapors formed by a liquefied gas. This quenching method has application to all metals, alloys, and materials which require rapid cooling to develop the physical characteristics desired, such as: full hardness, strength, and corrosion resistance for heat-treatable aluminum alloys, copper alloys, and any other heat-treatable precipitation-hardening material; optimum ductility and corrosion resistance for all materials that will become embrittled and sensitized as a result of slow cooling such as austenitic, ferritic and martensitic stainless steels, heat, corrosion and oxidation-resistant alloys, and other materials subjected to heat treatment; and full hardness, toughness, strength, ductility for all materials which experience a microstructural transformation during cooling. These materials include the carbon, low-alloy, tool and die steels, and cast irons, and the like.

In the practice of my invention I find it preferable to use liquid nitrogen as the quenching medium because of its relatively low-cost and because it can be handled with standard equipment; however, it is within the spirit and scope of my invention to use any suitable liquefied gas or the vapors formed by such a liquefied gas, or any of the other cryogenic fluids known in the current low-temperature technology. If a liquefied gas is used, a dip tank suitably modified to reduce evaporation and splashing may be employed to contain the quenching medium. Should a vapor quench be used, a vapor quenching chamber employing principles well known in the art can be used in my quenching method. Because the time factor is critical in this quenching method, as it is in the conventional quenching methods, it is essential that the dip tank or the vapor quenching chamber be located as close to the heat treat furnace as possible.

In the method of my invention, as in conventional metal treatment processes, the part is heated by suitable means to the so-called solution heat-treating temperature and is maintained at that temperature for a period of time sufficient to cause at least a part of one or more of the constituents of the material to melt or "go into solution." The temperature and the length of time the part is kept at that temperature are, of course, dependent upon the material of the part undergoing treatment, the thickness of the metal in the part, the heating medium used, and the circulation of the heating medium. When the heating step has been completed, the part is then taken from the heating means and plunged directly into the liquid nitrogen contained in the dip tank. As stated previously, the time factor between the heating operation and the quench is critical in that the best metallurgical properties are attained when the part is taken as rapidly as possible from the solution heat treating temperature level to a cryogenic temperature level. Any time lag between these two steps will affect adversely the attainment of the physical benefits achievable with my quenching method. After the part has cooled to the temperature of the quenching medium, it is removed from the dip tank. When a liquid nitrogen quench is used, a marked decrease in the amount of boiling or agitation of the liquid nitrogen influenced by the part is an indication that the part has reached the temperature of the quench. It is to be noted that tests I have conducted seem to indicate that the physical properties desired are obtained if the part is rapidly cooled below approximately —50° F. Thus, in many instances, it is not necessary to cool the part to the temperature of the quench; however, in order to simplify process control, I find it preferable to leave the part in the quench until it reaches the temperature of the quenching medium. If required, the part may be age hardened after the quench.

Tests have confirmed that the method of my invention has produced parts having the favorable physical characteristics of conventional water quenched parts but without the distortion of such water quenched parts. As an example of the comparative tensile properties produced by my method and a conventional water quench, the following values were obtained in tests involving 48 specimens consisting of .063-inch bare aluminum alloy sheet of the type commonly known at 2024 alloy. The specimens were solution heat treated in salt and after a period of 2½ seconds following removal from the solution heat-treat, were quenched vertically either parallel or perpendicular to their grain direction in their respective quenching medium. This time period was selected for convenience and was kept constant for all specimens throughout the test so as not to introduce an additional variable.

For a run of 12 transverse specimens, water quenching produced an average ultimate strength of 68,100 p.s.i., the 0.2% yield strength averaged 42,550 p.s.i., and the elongation averaged 18.4%. For the same number of transverse specimens, the cryogenic quench of my method using liquid nitrogen as the quenching medium produced an average ultimate strength of 68,300 p.s.i., the 0.2% yield

strength averaged 43,350 p.s.i., and the elongation averaged 18.3%.

For a run of 12 longitudinal specimens, water quenching produced an average ultimate strength of 68,950 p.s.i., the 0.2% yield strength averaged 42,200 p.s.i., and the elongation averaged 17.6%. The liquid nitrogen quench of my method produced in 12 longitudinal specimens an average ultimate strength of 70,000 p.s.i., a 0.2% yield strength averaging 43,800 p.s.i., with an average elongation of 18.2%.

These tests thus indicate that the cryogenic quench of my invention resulted in slightly higher tensile properties in this particular aluminum alloy as compared with a conventional water quench. Tests with other aluminum alloys, on the other hand, have indicated that a conventional water quench produced slightly higher tensile properties. However, in any of these tests, the variations in strength were only in the order of a few hundred pounds per square inch and in no case did the strength levels fall below those specified for that particular alloy.

In addition, experimental data indicates satisfactory results with my method in the treatment of aluminum alloys of the type commonly known as 2014, 6061, 7075 aluminum alloys, in vanadium modified low alloy steel of the type commonly termed 4330 vanadium steel, and in stainless steels of the type commonly known as type 416 and 431.

From my observations more favorable physical properties in the part can be obtained should a more rapid heat extraction be achieved by increasing the heat transfer rate of the quench. This, in turn, may be achieved by promoting the agitation or bubbling action of the quenching medium. It appears that the change of state of the fluid involved in the agitation or bubbling action accelerates the extraction of heat from the part to thus produce improved physical properties. This conclusion appears to be borne out by tests I have conducted in which I have induced a bubbling action in the quenching medium prior to introducing the part being treated. This intensifies the bubbling action resulting from immersion of the part in the quenching medium. These tests indicate that an improvement and greater uniformity in the physical properties of the part are attained with an increase in the agitation or bubbling action of the quench. I have found that an ultrasonic transducer is a satisfactory source of energy for inducing the bubbling action of the quenching medium to achieve an increased heat transfer rate. However, while I found that an ultrasonic transducer will produce satisfactory results, I am aware that other means for producing vibratory energy and mechanical agitation may be suitably employed. I am also aware that chemical additives, such as carbon dioxide, may also be used to agitate the quenching medium.

Although described in what is believed to be the most practical and preferred embodiments, it is apparent that departures from the specific method described will suggest themselves to those skilled in the art and may be made without departing from the spirit and scope of the invention. I, therefore, do not wish to restrict myself to the particular method described, but desire to avail myself of all modifications that may fall with the scope of the appended claims.

Having thus described my invention, what I claim is:

1. The method of treating a sheet metal part made of an alloy having at least one hardening constituent which comprises subjecting the part to a solution heat treatment, and thereafter introducing said part at substantially the temperature of the solution heat treatment directly into a cryogenic quenching medium to reduce the temperature of said part as rapidly as possible below approximately —50° F.

2. The method of treating a sheet metal part made of an alloy having at least one hardening constituent which

comprises subjecting the part to a solution heat treatment, and thereafter introducing said part at substantially the temperature of the solution heat treatment directly into a cryogenic quenching medium, the temperature of which is below approximately —50° F., to reduce the temperature of said part as rapidly as possible to the temperature of said quenching medium.

3. The method defined in claim 1 wherein the cryogenic medium is a liquefied gas.

4. The method defined in claim 1 wherein the cryogenic medium is a vapor formed from a liquified gas.

5. The method defined in claim 3 wherein the liquefied gas is nitrogen.

6. The method defined in claim 4 wherein the vapor is formed from liquified nitrogen.

7. The method defined in claim 1 wherein the alloy is an aluminum base alloy.

8. The method defined in claim 1 wherein the alloy is steel.

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