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ALLOY STEEL AND METHOD

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This invention is concerned with the high alloy steels and more particularly the heat-hardenable chromium-nickel alloy steels.

Among the objects of my invention is the provision of a chromium-nickel-molybdenum alloy steel which is fully austenitic under all conditions of heat-treatment; which steel readily lends itself to forming, shaping and other fabrication in the annealed or solution-treated condition; and which following shaping, forming or other fabrication, is thereafter quickly, economically and reliably hardened and strengthened by way of a simple and comparatively low-temperature heat-treatment of relatively short duration, giving articles and products which are suited to room temperature duty and duty at elevated temperatures as well.

Other objects of my invention will be obvious in part and in part more fully pointed out during the course of the description which follows.

Accordingly, my invention resides in the combination of elements, in the compositions of materials, in the several operational steps, and in the relation of each of the same to one or more of the others as described herein, the scope of the application of which is indicated in the claims at the end of this specification.

As conducive to a better understanding of certain features of my invention, it may be noted at this point that known chromium-nickel alloy steels have a chromium content something above 0% on up to about 35% and a nickel content of something above 0% on up to about 25%. Of these steels, the well-known stainless steels are defined as having a chromium content ranging from about 10% to 35% with a nickel content ranging from something above 0% on up to 25% or more. Nickel is included for the dual purpose of improving the stainless qualities of the steel and controlling the structure of the steel. With nickel high the steel is essentially austenitic. Where nickel is low relative to chromium, the metal is either typically martensitic or ferritic, depending upon the carbon content. It is the austenitic stainless steel which possesses maximum ductility and formability.

In the known chromium-nickel alloy steels various alloying metals may be included in small amounts to impart special properties. Mention is made of aluminum, copper, molybdenum, manganese, cobalt, silicon, sulphur, phosphorus, tungsten, vanadium, titanium, columbium and the like. The remainder of the composition is substantially all iron. Usually the steels are of low carbon content, say about 0.03% to a maximum of about 0.20%. Where desired, however, the carbon content may be substantially higher.

Perhaps the best known chromium-nickel stainless steel is the 18–8 grade. This, of course, is characteristically austenitic. It is non-magnetic. It, however, hardens upon working by known forming, working or machining operations at room temperatures. Moreover, it work-hardens as by riveting, or like joining treatment. In many applications this is considered to be a disadvantage, particularly where the working operation must be frequently interrupted to relieve the strains induced by working, as by subjecting the metal to intermediate anneal with possible loss of the dimensionality through light scaling, or distortion.

Furthermore, the known steel, by virtue of its high total alloy content, notably its high values of both chromium and nickel, is virtually immune to phase-transformation when subjected to heating and a subsequent quench, the soft austenitic condition, characteristic of the steel, being retained throughout heat-treatment. In short, the steel is not hardenable by heat-treating methods to improve strength and hardness. And, in some respects this is considered a further disadvantage.

Another disadvantage of the known austenitic chromium-nickel stainless steels is that upon rolling, drawing, or other work conducted in a single direction, the work-hardening effect essentially lies along the direction of working; in the transverse direction the mechanical properties are not developed to the same extent as those in the working direction. The disparity is particularly noted in compression. And in many applications any substantial difference in the longitudinal and transverse compressive strengths is not acceptable.

The steel, although eminently suited to room temperature duty, is not particularly suited to high temperature applications; it is lacking in strength at temperatures exceeding 800° F.

As contrasted with the well-known austenitic chromium-nickel stainless steels, there are the precipitation-hardenable grades, that is, the chromium-nickel stainless steels which are hardenable by heat-treatment. Typical of these are the Armco 17–7PH (about 17% chromium, 7% nickel, 1% aluminum, and remainder iron), the Armco 17–4PH (about 17% chromium, 4% nickel, 4% copper, and remainder iron) and the Armco PH15–7Mo (about 15% chromium, 7% nickel, 2% molybdenum, 1% aluminum, and remainder iron).

In their annealed conditions, these steels possess good working and forming characteristics. And in their hardened conditions the steels display many highly desirable physical properties. Illustratively, the steels are hard, durable and of high tensile strengths. They, however, are not austenitic and are not free of magnetic effects. And they are not suited to duty at temperatures above about 900° F.

The straight chromium grade with about 12% chromium and remainder iron, and the 16–2 chromium-nickel grade, both of which are in common usage, are neither austenitic nor easily formable. Moreover, while suited to certain applications at temperatures up to about 1150° to 1200° F., as in turbine blading, these two steels are not calculated to serve well at temperatures exceeding those figures. And hardening is had by heat-treatment only at high temperatures, that is, heating at about 1800° F. and quenching for the 12% chromium grade, at about 1900° F. and quenching for the 16–2 chromium-nickel grade.

Therefore, one of the objects of my invention is to provide a chromium-nickel alloy steel which, in the annealed condition, readily lends itself to fabrication into a variety of articles by pressing, bending, cold-upsetting, punching, machining, threading and the like, which articles then are hardenable by heat-treatment at comparatively modest temperatures and in substantial absence of scaling and physical distortion, all without loss of the austenitic quality of the metal.

Turning now to the practice of my invention, I find that with a proper combination of molybdenum, chrominum and nickel, I achieve an austenitic steel which is subsequently hardenable by heat-treatment from a soluble solution- treated (annealed) condition. And that this hardening is had by way of a single-step hardening operation of comparatively short duration conducted at relatively low temperatures.

The hardened steel is fully austenitic and non-magnetic. And the mechanical properties of the steel compare favorably with known precipitation-hardened steels.

More particularly, the alloy steel of my invention es-

sentially consists of chromium about 5% to 14%, nickel exceeding 10% but not exceeding 25%, molybdenum about 6% to 25%, with remainder substantially all iron. Carbon is included in amounts up to about 0.12% and nitrogen in amounts up to about .150%. Manganese also may be present in amounts up to about 6%. Phosphorus is present in amounts up to 0.05% maximum, sulphur up to 0.05% maximum, and silicon up to about 2.00%. Where desired, columbium and tantalum are employed in total amount up to about .75%. Copper may be present in amounts up to 3.0%.

In the steel of my invention the percentages of chromium, nickel and molybdenum and the relationships between the same, are all critical. For if nickel content is substantially less than the required minimum the austenitic balance suffers and where it substantially exceeds the maximum figure the steel becomes too costly; moreover, hardenability suffers. And if the steel is either too low in chromium or too high in molybdenum, practical difficulties are encountered. I find, however, that with a chromium content near the lower part of the given range molybdenum may be somewhat higher than would otherwise be permissible; while if the chromium content approaches the upper limit of permissible range, then the molybdenum content must be correspondingly diminished.

The steel of my invention displays requisite softness and ductility following a preliminary solution-treatment, that is, an anneal, as by heating for about one-half hour at temperatures of about 1600° F. to 2000° F. and quenching in air or water. The steel is fully austenitic. In this condition the steel can be worked by known methods, such as pressing, bending, cold-upsetting, punching, machining, threading, and the like. And the resulting products readily lend themselves to hardening by a simple ageing treatment conducted at comparatively low hardening temperatures and enduring for relatively short periods of time, particularly 1100° F. to 1500° F. for an hour or more and cooling as in air or water. The hardened products thereby acquire enhanced qualities of hardness and strength.

A preferred chromium-nickel-molybdenum alloy steel according to my invention analyzes about 9% to 11% chromium, about 13% to 15% nickel, about 11% to 13% molybdenum, carbon up to 0.12%, nitrogen up to .150%, and remainder substantially all iron. Another preferred steel analyzes about 11% to 13% chromium, about 11% to 13% nickel, about 9% to 11% molybdenum, carbon up to 0.12%, nitrogen up to about .150%, and remainder substantially all iron. Further, a specific preferred steel analyzes about 10% chromium, about 14% nickel, about 12% molybdenum, about .03% carbon, about .05% nitrogen, and remainder substantially all iron. A further one analyzes about 12% chromium, about 12% nickel, about 10% molybdenum, about .03% carbon, about .05% nitrogen, and remainder substantially all iron. These steels are all considered as being stainless steels.

In its solution-treated or annealed condition the steel is in a fully austenitic condition with molybdenum in solution in the austenitic matrix. In the heat-hardened condition, that is, the condition had by the age-hardening, it appears that there has been a precipitation of a molybdenum-rich phase. It may be supposed that it is this precipitated phase, rich in molybdenum and distributed uniformly throughout the steel to which may be attributed the improved mechanical properties of hardness and strength. Unlike many known precipitation-hardened alloys, the steel of my invention retains these properties even following prolonged operation at elevated temperatures. This I attribute to the stability of the molybdenum-rich phase present in the hardened condition of the steel.

The analyses of two chromium-nickel-molybdenum

stainless steels according to my invention are given in Table I below:

TABLE I

Specific Examples of Austenitic Heat-Hardenable Chromium-Nickel-Molybdenum Stainless Steels

Heat No.	C	Mn	P	S	Si	Cr	Ni	Mo	N
R2432-2	.095	1.61	.026	.030	.54	12.23	11.70	9.62	.052
R2433-2	.098	1.18	.022	.021	.84	12.26	13.62	12.27	.047

The steels identified in Table I were first annealed at 2000° F. for ½ hr. and water quenched. Following this they were heated at 1400° F. for 10 hours and air-cooled. The hardness of the samples in the annealed condition and the hardness in the heat-hardened condition are given in Table II below:

TABLE II

Solution-Treated Hardness and Heat-Hardened Hardness of the Steels of Table I

Heat No.	Condition—2000° F.-½ hr.-W.Q.	Condition—1400° F.-10 hrs.-air cool
R2432-2	Rockwell B93	Rockwell C27.
R2433-2	Rockwell B90	Rockwell C33.

It will be seen that the steel in the solution-treated condition is quite soft (Rockwell B93 or less). In the heat-hardened condition, however, substantial hardness, and strength, are had. The austenitic quality is maintained. And articles fashioned of the steel are eminently suited to applications where both strength and freedom from non-magnetic effects are required. The high temperature mechanical properties also are good. As a consequence, while the known grades of precipitation-hardened chromium-nickel stainless steels are generally not suited to applications where there are encountered temperatures exceeding 800° to 900° F., and the usual heat-resisting steels such as the straight 12% chromium grade and even the 16–2 chromium-nickel grade, are not suited to duty above 1150° to 1200° F., my steel is intended for applications of service at temperatures up to 1350° F. and, for short periods of time, temperatures up to 1500° F. or more. The steel thereof lends itself to the production of various steam turbine and gas turbine applications as well as various fastening devices or turbine and other applications, particularly high tempered bolts, screws, nuts, studs, and the like.

Accordingly, therefore, it will be seen that I provide in my invention a steel and method of heat-treating the same, in which the many objects and advantages hereinbefore set forth are successfully achieved. My steel is ductile, soft and lends itself to a variety of working and forming operations. In the heat-hardened condition it is well suited to duty at room temperatures, as well as at elevated temperatures. In my steel there is had a good resistance to corrosion, even when subjected to reducing acids. And, it is to be noted, the improvement in corrosion resistance is without sacrifice of the precipitation-hardenable qualities. In the hardened condition the steel achieves considerable resistance to wear, abrasion and galling.

The steel of my invention lends itself admirably to the production of castings as well as wrought products. The metal in the solution-treated or annealed condition is fully austenitic, is free of delta-ferrite, and whether in cast condition or wrought, can be machined with comparative ease. Also it can be welded with ease and with good result.

My steel is particularly suited to use in chemical processing equipment such as scrubbing towers, fume handling equipment, and the like. The steel and various pieces

of apparatus and equipment fashioned thereof is especially adapted to withstand the corrosive attack of halogen compounds such as hydrochloric acid liquids and fumes. Particularly good results are had where the molybdenum content amounts to 15% or more, for I find that a sharp increase in the resistance to halogen compounds is had with the high molybdenum content, with resistance to pitting by such compounds effectively assured. The steel then essentially consists of chromium 5% to 9%, nickel 17% but not exceeding 25%, molybdenum 15% to 25%, and remainder substantially all iron.

Inasmuch as many embodiments may be made of my invention and inasmuch as many changes may be made in the present embodiment, it will be understood that I desire the foregoing disclosure to be considered as simply illustrative, and not as a limitation.

I claim as my invention:

1. Non-magnetic alloy steel which is fully austenitic, ductile and readily workable after solution-annealing at a temperature of about 1600° to 2000° F. and which is precipitation-hardenable to achieve hardness and strength by thereafter merely ageing at a temperature of about 1100° to 1500° F. without loss of non-magnetic characteristics, said alloy steel essentially consisting of chromium 9% to 11%, nickel 13% to 15%, molybdenum 11% to 13%, carbon up to .12%, nitrogen up to .150%, and remainder substantially all iron.

2. Non-magnetic alloy steel which is fully austenitic, ductile and readily workable after solution-annealing at a temperature of about 1600° to 2000° F. and which is precipitation-hardenable to achieve hardness and strength by thereafter merely ageing at a temperature of about 1100° to 1500° F. without loss of non-magnetic characteristics, said alloy steel essentially consisting of chromium 11% to 13%, nickel 11% to 13%, molybdenum 9% to 11%, carbon up to .12%, nitrogen up to .150%, and remainder substantially all iron.

3. Non-magnetic alloy steel which is fully austenitic, ductile and readily workable after solution-annealing at a temperature of about 1600° to 2000° F. and which is precipitation-hardenable to achieve hardness and strength by thereafter merely ageing at a temperature of about 1100° to 1500° F. without loss of non-magnetic characteristics, said alloy steel essentially consisting of chromium about 10%, nickel about 14%, molybdenum about 12%, carbon about .03%, nitrogen about .05%, and remainder substantially all iron.

4. Non-magnetic alloy steel which is fully austenitic, ductile and readily workable after solution-annealing at a temperature of about 1600° to 2000° F. and which is precipitation-hardenable to achieve hardness and strength by thereafter merely ageing at a temperature of about 1100° to 1500° F. without loss of non-magnetic characteristics, said alloy steel essentially consisting of chromium, about 12%, nickel about 12%, molybdenum about 10%, carbon about .03%, nitrogen about .05%, and remainder substantially all iron.

5. Non-magnetic alloy steel which is fully austenitic, ductile and readily workable after solution-annealing at a temperature of about 1600° to 2000° F. and which is precipitation-hardenable to achieve hardness and strength by thereafter merely ageing at a temperature of about 1100° to 1500° F. without loss of non-magnetic characteristics, said alloy steel essentially consisting of chromium 5% to 9%, nickel 17% but not exceeding 25%, molybdenum 15% to 25%, and remainder substantially all iron.

6. Non-magnetic, age-hardened austenitic stainless steel articles essentially consisting of chromium 11% to 13%, nickel 11% to 13%, molybdenum 9% to 11%, carbon up to .12%, nitrogen up to .150%, and remainder substantially all iron.

7. Age-hardened austenitic alloy steel articles particularly resistant to the corrosive attack of halogen compounds, said steel articles essentially consisting of chromium 5% to 9%, nickel 17% but not exceeding 25%, molybdenum 15% to 25%, and remainder substantially all iron.

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