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TITANIUM-BEARING CHROMIUM-NICKEL-COPPER STAINLESS STEEL

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ABSTRACT OF THE DISCLOSURE

Chromium-nickel-copper stainless steel, additionally containing titanium, and of such composition balance, i.e, amount and relation between the several ingredients chromium, nickel, copper and titanium, as to be comparatively ductile and readily workable in one condition of heat-treatment (annealed condition) with a minimum of hardening during such working and yet readily precipitation-hardened within the cold-worked portions thereof by simple heat-treatment at comparatively low temperatures (below the temperature resulting in heat tint and scaling), giving desired articles of ultimate use with hardened surfaces but with other portions of good retained ductility and toughness. More particularly, steel, and articles fashioned thereof, essentially consisting of 10% to 25% chromium-molybdenum, with chromium at least 10% and molybdenum up to 5%; 5% to 20% nickel-manganese, with nickel at least 4% and manganese up to 15%; 1% to 5% copper; .3% to 4% titanium; and remainder substantially all iron.

CROSS-REFERENCE TO RELATED APPLICATION

This application is a division of my copending application Ser. No. 411,730, filed Nov. 17, 1964, and entitled Stainless Steel and Method, now U.S. Letters Patent 3,357,868 of Dec. 12, 1967.

INTRODUCTION

My invention is concerned with the austenitic chromium-nickel stainless steels which are hardenable by heat-treatment and with a variety of hardened articles fashioned thereof.

One of the objects of the invention is the provision of a chromium-nickel stainless steel which works well in the mill as in the production of sheet, strip, plate, bars, rods, wire and special shapes; which steel then is readily formed through cold-working operations such as drawing, upsetting, heading, rolling, spinning and the like, all without necessity for intermediate annealing treatment; and which steel, while hardening but modestly during such cold-working or cold-forming operations, nevertheless in cold-worked or cold-formed condition is susceptible to subsequent hardening by heat-treatment.

Another object of my invention is the provision of an austenitic chromium-nickel stainless steel and a wide variety of cold-worked instrument springs, industrial springs and the like; a variety of cold-worked threaded fastening devices such as screws, bolts, etc., wherein the threaded portions thereof are rolled-on and the head portions upset; which steel and articles harden but modestly in cold-work with minimum wear on forming dies; and which steel and articles may then be hardened by heat-treatment at but moderate temperatures, all of which shapes, springs, fastening devices and the like are strong, tough, hard and abrasion-resistant and are well adapted to withstand corrosion, wear and the stresses generally encountered in practical actual use.

A further object is the provision of screws of such

surface hardness and abrasion-resistance and of such internal toughness and strength, as to serve in the tapping of metal parts such as sheet metal roofing, sidings and the like, and sheet metal housings for refrigerators, washing machines and other appliances, and then secure and fasten the same together.

Other objects of my invention in part will be obvious and in part particularly pointed to during the course of the description which follows.

My invention, therefore, resides in the combination of elements, in the mixture of ingredients and in the relation between the same; in the various cold-working or cold-forming steps; in the various heat-treating steps; and in the relation between composition, forming and heat-treatment, all as described herein, the scope of application of which invention is set out in the claims at the end of this specification.

BACKGROUND OF THE INVENTION

In order to gain a better understanding of certain features of my invention, it may be noted here that the stainless steels have found great favor in the art. Actually, there are available some 30-odd types variously suited to different practical applications. Many of these steels are work-hardening, that is, they harden during cold-working and cold-forming operations. For example, the American Iron & Steel Institute Type 305 (about 18% chromium, 11% nickel, and remainder iron) has a relatively low work-hardening rate. Nevertheless, with a 60% reduction in area a hardness on the order of Rockwell C50 is had. In any substantial working or forming of that steel several intermediate and costly annealing treatments are required. Moreover, that steel cannot be significantly hardened by heat-treatment.

The straight-chromium grades of stainless steel, for example Type 430 (about 17% chromium and remainder iron) as well as the Type 410 (about 12% chromium and remainder iron), although not inclined to harden as a result of cold-working operations, are not disposed to harden by ageing treatment either, that is, treatment at rather modest temperatures. Hardening of these steels is had by heating to high temperatures, that is, temperatures on the order of some 1800° F., and quenching. Such high temperature heat-treatment is inclined to cause scaling, which scale must be removed at significant expenditure of time and money. The structure is martensitic.

The more complex chromium-nickel stainless steels, for example, the chromium-nickel-copper-aluminum stainless steels made the subject of the Tanczyn U.S. Pat. 2,694,626 of Nov. 16, 1954, although age-hardenable, are characterized by an objectionably high work-hardening rate. That steel, like the other chromium nickel steels, because of a high work-hardening rate, is not suited to drastic cold-deformation and subsequent ageing to develop great hardness.

While self-tapping stainless steel screws are known to the art, these customarily are made of the 12% chromium grade of stainless steel. And the screws, subsequent to forming, are hardened by heating at about 1800° F. and quenching. Following this, they are relieved of quenching stresses by reheating at a temperature of about 400° F. to 600° F. The hardening treatment, however, is inclined to leave a heat-scale on the metal as noted above, with the result that the metal must be cleansed before use. Moreover, these self-tapping screws are hardened throughout and for this reason are somewhat brittle. Although less brittleness would be had with the known chromium-nickel stainless screws fashioned thereof, they would lack the hardness required for the self-tapping screws.

Accordingly, one of the objects of my invention is the provision of a chromium-nickel stainless steel of such

composition balance as to be but moderately hardenable as a result of cold-deformation through cold-working and cold-forming operations; which cold-worked or cold-formed steel then readily lends itself to age-hardening or precipitation-hardening by heat-treatment at moderate temperatures, i.e., temperatures not sufficiently high to cause formation of objectionable heat-scale; which steel and articles fashioned thereof are possessed of great surface hardness and abrasion-resistance, yet interiorly thereof are tough, ductile and adapted to withstand the stresses encountered in use; and which steel in the cold-worked and age-hardened condition is pecularly adapted to withstand corrosive effects encountered in use, including those of galvanic action.

SUMMARY OF THE INVENTION

Giving attention now to the practice of my invention, I provide a chromium-nickel stainless steel which essentially includes the further ingredient copper along with the ingredient titanium. My steel consists essentially of a chromium-like metal in the amount of 10% to 25%, a nickel-like metal in the amount of 5% to 20%, copper in the amount of 1% to 5%, titanium in the amount of .3% to 4%, with remainder substantially all iron. Now the chromium-like metal is chromium with or without the further ingredient molybdenum. In every instance the amount of chromium itself must be at least 10%. And the amount of molybdenum which may be included as a part of the chromium-like metal must not exceed 5%. Where molybdenum is employed along with chromium, replacement of molybdenum for chromium is on the basis of 1 to 1.

The nickel-like metal consists of nickel with or without the further ingredient manganese. The amount of nickel itself must be at least 4%. And where manganese is employed as a partial substitute for nickel, the substitution is on the basis of 2 for 1, with the total manganese content not exceeding 15%.

In the steel of my invention carbon, of course, is present, this amounting up to some 0.20%. Best results, however, are had where the carbon content does not exceed about 0.10%, particularly where it does not exceed about 0.05%, for reasons given below. Nitrogen also is present in small amounts, that is, amounts up to .25%, although here again, best results are achieved where the nitrogen content does not exceed 0.10%, and particularly where it does not exceed 0.05%, for I find that both of the ingredients carbon and nitrogen tend to increase the hardness of the steel in the annealed condition. And such necessitates additional working and forming to achieve a desired amount of plastic deformation. Any substantial carbon content, for example, carbon in excess of the 0.20% max. permissible figure, additionally would require objectionably high annealing temperatures in order to take the carbon into solution. And an excess of nitrogen additionally would run the risk of gas evolution on freezing of the ingot with consequent unsoundness in the final product.

Silicon, likewise is present in my steel, this in amounts up to 2%. So, too, manganese is present in amounts up to 1%, even where there is no purposeful manganese addition.

Phosphorus and sulfur are present in my steel, each up to a maximum of about 0.05%, although in steels requiring cold-heading or cold-upsetting operations the sulphur content should not exceed 0.02%. The ingredients sulphur and phosphorus, along with selenium, bismuth, tellurium and silver, may be present in sum total up to about 0.50% as a maximum, to lend improved machinability to the metal, where required. But these additions are not included in the steel where cold-heating operations or other cold-upsetting operations are resorted to, or where significant bending stresses are contemplated. In general, my steel is free of these additions.

The steel of my invention additionally may contain

purposeful additions of boron in amounts up to 0.009% for improved hot-working properties in the presence of the high total alloy content. Zirconium also may be included where desired in amounts up to about 1%, to obtain an improvement in age-hardenability.

Now in my steel I employ a particular balance or relationship between the chromium-like component, on the one hand, and the nickel-like component, on the other. I find that where there is a high ratio between the chromium-like content and the nickel-like content, substantially uniform elongation is achieved in working, but the work-hardening rate is unduly high; such a steel has a high work-hardening factor.[1] Where, however, the ratio between the chromium-like and the nickel-like ingredients is low, that is, less than 1, the elongation of the metal is not uniform; it tends to neck down. And even though the rate of work-hardening is acceptable, the steel is not satisfactory.

In the steel of my invention the work-hardening factor amounts to about 85, this falling well below the 162 work-hardening factor of the Type 301 steel (17% chromium, 7% nickel, and remainder iron), a steel of objectionably high work-hardening rate. It falls very close to the very low work-hardening factor of 80 which is had in a 16–18 steel (16% chromium, 18% nickel, and remainder iron). This latter steel, however, is subject to objectionable localized elongation.

While the balance between the chromium-like and the nickel-like components of my steel is generally such that the steel in the annealed condition is non-magnetic, a balance substantially exceeding 2 is inclined to give a duplex structure, wherein the metal does not work well in the hot-mill. It is inclined to break and tear through the ferrite constituent.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now in the cold-worked and age-hardened condition, my steel may become magnetic or it may remain non-magnetic, this depending upon the particular balance of ingredients. For the magnetic steel I employ a nickel-like content (nickel plus ½ the maganese) of about 13% to 16% for a chromium-like content (chromium plus molybdenum) of about 10%, a nickel-like content of about 8% to 14% for a chromium-like content of about 12%, a nickel-like content of about 7% to 13% for a chromium-like content of about 16%, a nickel-like content of about 6.5% to 9.5% for a chromium-like content of about 19%, and a nickel-like content of about 5% to 6% for a chromium-like content of about 22%. In these steels the copper content amounts to about 3% and the titanium content about 1%, although in general some latitude is desirable. In general, the copper ranges from about 2% to 4%, permissibly from about 1% to 5%, and the titanium from about .5% to 2%, although permissibly from about .3% to 4%.

All of the above magnetic steels are essentially austenitic in the annealed condition, although the steel of 22% chromium content does contain some ferrite. When subjected to drastic cold-deformation, however, all of these steels become martensitic and magnetic. This condition obtains even in the steel of 10% chromium content with a nickel content of 13% to 16% where the cold-deformation amounts to as much as 70%. These steels, of course, remain martensitic and magnetic even after a subsequent age-hardening treatment.

In the magnetic steels I may partially substitute manganese for nickel, this on a 2 to 1 basis, as noted above. Where the chromium content of the particular steel is below 16%, the manganese content may be as much as

[1] "The Cold-Work-Hardening Properties of Stainless Steel in Compression," by Bloom, Goller and Mabus: 1947 Transactions A.S.M., volume 39, page 843.

12%, this being substituted for 6% nickel. But where the chromium content is about 16%, no more than about 8% manganese may be employed, this as a substitute for 4% nickel. In these steels it will be understood, as previously indicated, that the actual nickel content must be at least 4% in order to enjoy the desired combination of work-hardening and age-hardening properties.

And in the non-magnetic steel, i.e., the steel which is non-magnetic in the annealed condition, non-magnetic in the work-hardened condition and non-magnetic in the age-hardened condition, I employ a nickel-like content (nickel plus ½ the manganese) of 14% to 20% for a chromium-like content (chromium plus molybdenum) of 12%, a nickel-like content of 12% to 20% for a chromium-like content of 16%, a nickel-like content of 11% to 20% for a chromimum-like content of 19%, a nickel-like content of 14% to 20% for a chromium-like content of 22%, and a nickel-like content of 15% to 20% for a chromium-like content of 25%. In each of these steels the copper content amounts to about 3% and the titanium content about 1%, although the copper may range about 1% to 5%, preferably 2% to 4%, and the titanium from about 1% to 4%, preferably about 2% to 3%.

In the non-magnetic steel, here again, manganese may be partially substituted for nickel up to about 15% of manganese, this for 7.5% nickel. The actual nickel content, however, as previously indicated, must be at least 4%.

In my steel the amounts of the ingredients chromium, nickel, copper and titanium, as well as the amounts of the ingredients molybdenum and manganese, which may be partially substituted for chromium, and nickel, respectively, are in every sense critical. So, too, is the relation between the several ingredients. As noted above, the chromium-like component ranges from about 10% to 25%, with the actual chromium content being at least about 10%. Where the actual chromium content is less than the 10% figure, and more particularly where it is less than 12%, the required corrosion-resistant qualities are not had. And where the chromium-like component exceeds the 25% figure, I find that the nickel requirements necessary become excessive in order to achieve the combination of work-hardening and age-hardening. The chromium content of my steel preferably ranges from about 14% to 19%.

While the molybdenum content of my steel may range up to about 5% as a partial substitute for chromium, an amount in excess of the 5% figure is not acceptable because excessive hardening is had, with loss of cold-working properties.

Now the nickel-like component, as noted above, ranges from about 5% to 20%. The actual nickel content, however, where manganese is partially substituted for nickel, may not be less than about 4% for otherwise, the steel becomes unstably austenitic and desired combination of work-hardening and age-hardening is not had. The manganese substituent may not exceed about 15%, actually, it may not exceed about 12% for the magnetic steels of chromium contents below about 16% and may not exceed about 8% for the steel of chromium content above about 16%, as previously noted, for I find that higher manganese contents as well as higher nickel contents disturb the composition balance necessary to achieve the combination of initial work-hardening and subsequent age-hardening treatments.

In the steels of my invention copper serves to lower the work-hardening rate, that is, lower it to an acceptable figure. The copper content, while permissibly ranging from about 1% to 5%, preferably does not exceed about 4% because I find that amounts significantly above the 4% figure are inclined to adversely affect the hot-rolling properties of the metal; apparently the limit of solubility for copper is about 4%, and any excess appears as free copper, introducing a liquid phase with resulting breaking in the mill unless the hot-rolling operation is conducted at an undesirably lowered temperature. A copper content below the 1% figure has no beneficial effect. Best results are had with a copper content of about 2% to 4%, as previously noted.

The titanium content of my steel permissibly ranges from about .3% to 4%. Below the .3% figure there is no beneficial precipitation-hardening effect, and above a figure of 4%, the nickel requirement again becomes excessive. I find that a best combination of results is had where the titanium content ranges from about 2% to 3%.

The steel of my invention conveniently is melted in the electric arc furnace or in the vacuum are furnace. The steel handles well in the furnace, teems well and the mold strips from the ingot with ease.

The ingots, blooms, billets, and the like, work well in the hot-mill at conventional rolling temperatures, as in the production of plate, sheet, strip, bars, rods, wire and special shapes. The hardness of the metal in the hot-rolled condition and in the annealed condition is on the order of Rockwell B60–80. And upon cleansing, it is suited to a variety of cold-working and cold-forming operations. The sheet and strip is suited to rolling, deep-drawing, spinning, and the like. And the rods and wire are well suited to drawing and upsetting as in the production of screws, bolts and other headed and threaded fasteners. So, too, the metal is suited to rolling, cutting, and the like, as in the production of instrument springs and industrial springs, and washers. The metal lends itself to cutting, and other machining, as in the production of various machine parts.

In the cold-working and cold-forming operations the steel of my invention acquires significant but not excessive hardness; for a reduction of some 60% the hardness customarily increases up to about Rockwell C35 for the steels of such composition balance as to be martensitic and magnetic, and for like reduction, up to about Rockwell C31 for the steels which are of such composition balance as to be fully austenitic and non-magnetic.

Following the cold-working and cold-forming operation the steel is age-hardened, the ageing temperature employed being dependent upon the composition. For the steel and articles of magnetic composition balance, for example, 12% to 18% chromium, 7% to 11% nickel, 2% to 5% copper, .5% to 2% titanium, and remainder substantially all iron, hardening is achieved by heating the same at a temperature of about 700° F. to 900° F. and cooling in any one of air, oil or water. The cold-working operation sufficiently strained the metal to induce age-hardening by the comparatively low-temperature ageing treatment. My steel and articles are free of scale, or other objectionable surface effect. In the aged condition of the 60% cold-reduced metal the hardness had amounts up to about Rockwell C45–50.

Similarly, for the steel and articles of such composition balance as to be fully austenitic in the aged condition and free of magnetic effects, that is, the steel analyzing about 15% to 18% chromium, 11% to 15% nickel, 2% to 5% copper, 2% to 3% titanium, and remainder substantially all iron, ageing is achieved by heating the metal at a temperature of about 850° F. to 1250° F. and then quenching in air, oil or water. The hardness had there comes up to about Rockwell C35 to 45. Where desired, the steel may be overaged somewhat, as by ageing at 1300° F. and quenching and then cold-worked a limited extent to effect an increase in hardness, say from Rockwell C30 to 32 in overaged condition, to some C35 to 45 in final cold-worked condition. Such steel in overaged and work-hardened condition is suited to the production of fasteners, no heat-treating being required by the customer-fabricator of such fasteners.

As generally illustrative of the titanium-bearing steels of my invention as contrasted with closely related steels but containing columbium instead of the titanium, the chemical analyses of several specific examples of each are given in Table I below:

TABLE I.—CHEMICAL ANALYSES OF TWELVE Cr-Ni-Cu STAINLESS STEELS

Heat No.	I(a) Titanium Steels of the Invention								I(b) Columbium Steels							
	C	Mn	P	S	Si	Cr	Ni	Cu	Ti	Mo	C	Mn	P	S	Si	Cr	Ni	Cu	Cb	Mo
R4861(m)	.015	.92	.017	.003	.49	15.62	7.70	2.97	.66	------	.059	.96	.019	.011	.61	16.63	8.07	3.02	1.12	------
R4862(m)	.017	.94	.014	.004	.49	13.81	8.56	3.00	.58	------	.056	1.01	.020	.010	.53	15.46	15.18	3.05	3.19	------
R4863(m)	.014	.88	.012	.004	.42	12.03	10.61	2.97	.69	------	.015	.79	.019	.003	.54	15.62	7.66	3.09	.52	------
R4864(m)	.014	.98	.016	.003	.45	13.70	7.67	2.03	.62	2.02	.016	.79	.017	.004	.42	14.23	8.59	2.93	.59	------
R4500(m)	.053	1.13	.019	.017	.64	16.59	8.17	3.06	1.24	------	.015	.91	.017	.004	.49	12.31	10.56	2.97	.66	------
R4501(n-m)	.049	1.07	.018	.011	.57	15.58	15.16	2.98	2.18	------	.015	.96	.014	.004	.51	13.95	7.62	2.97	.80	2.13

NOTE.—(m) Magnetic in final hardened condition; (n-m) Non-magnetic in all conditions.

TABLE II.—HARDNESS OF THE Cr-Ni-Cu STAINLESS STEELS OF TABLE I

Heat Number	II(a) Titanium Steels of the Invention					II(b) Columbium Steels				
	Annealed [1] hardness, Rockwell	Cold drawn 40% hardness, Rockwell	Cold drawn 60% hardness, Rockwell	Cold drawn 40% aged,[2] Rockwell	Cold drawn, 60% aged [3]	Heat Number	Annealed [1] hardness, Rockwell	Cold drawn 40% hardness, Rockwell	Cold drawn 60% hardness, Rockwell	Cold drawn 40% aged,[2] Rockwell	Cold drawn 60% aged,[2] Rockwell	Cold drawn, 60% aged [3]
R4861 (m)	B64	C26	C32	C43	C53	R4494(m)	B80	------	C33	------	C46	C40
R4862(m)	B77	C27	C35	C45	C51	R4495(n-m)	B85	------	C31	------	C36	C35
R4863(m)	B69	C22	C30	C31	C42	R4857(m)	B76	C29	C33	C43	C50	------
R4864(m)	B79	C32	C36	C47	C54	R4858(m)	B75	C27	C35	C42	C48	------
R4500(m)	------	------	C32	------	C49	R4859(m)	B71	C25	C31	C32	C41	------
R4501(n-m)	B80	------	C32	------	C34	R4860(m)	B86	C32	C36	C42	C51	------

[1] Anneal 1,900°/1,950° F.—Water quench.
[2] Anneal plus 850° F. 5 hours and air-cool.
[3] Anneal plus 1,150° F. 5 hours and air-cool.

NOTE: (m) Magnetic in aged condition.
(n-m) Non-magnetic in all conditions.

The hardness of the steels of Table I in the annealed condition, the hardness had when reduced 40% and when reduced 60%, and the final hardness in the age-hardened condition both for the 40% reduced steels and the 60% reduced steels are given in Table II below. In each instance the hardness data was developed on wire, which prior to cold-reduction was of ⅜" diameter by 15" length.

It will be seen from the test data presented above that in the annealed condition no particular difference in hardness is apparent between the titanium-bearing steels of my invention and the columbium-bearing steels. There, however, is some difference between the steels on the basis of whether the composition is such that it will be magnetic in the final cold-reduced and aged condition or will be non-magnetic in that condition. Thus, in the annealed condition the hardness is somewhat lower for the magnetic steels (Rockwell B64–77 for the magnetic titanium-bearing steels R4861 and R4862 as compared to Rockwell B82 for the non-magnetic titanium-bearing steel R4501).

In the cold-worked condition with 60% cold-reduction, all steels whether ultimately magnetic or non-magnetic and whether of low or significant carbon contents are seen to have a hardness of about Rockwell C30–35. With molybdenum also present somewhat higher hardness is had, namely Rockwell C35–36.

When aged, following work-hardening, the martensitic and magnetic steels of both the titanium-bearing steel of my invention and the columbium-bearing steels (heating at 850° F. and air-cooled) have a hardness of some Rockwell C42–45 for the steels with 40% cold-reduction. For the steels with 60% cold-reduction, however, the difference in hardness is in favor of the titanium-bearing steel (Rockwell C51–53 for the titanium-bearing steels R4861 and R4862 as compared to Rockwell C48–50 for the columbium-bearing steels R4857 and R4858 of like composition except for columbium substituted for titanium).

The non-magnetic steels when aged (850° F. and air-cooled) following the 60% cold-reduction, have a hardness of some Rockwell C34–36 for both the titanium-bearing and columbium-bearing steels. The non-magnetic titanium-bearing steels, however, achieve a greater hardening when aged at significantly higher temperatures while the columbium-bearing steels display little difference with the increased ageing temperature, although the hardness had still falls short of that achieved in the magnetic stainless steels. Thus the titanium-bearing steel R4501 of my invention when aged at 1150° F., following a 60% cold-reduction, is found to have a hardness of Rockwell C43 as compared to the Rockwell C34 figure when aged at 850° F. With the columbium-bearing steel R4495 the hardness amounts to some Rockwell 35–36 whether aged at 850° F. or at 1150° F.

With the magnetic steels there is a substantial loss in hardness through raising the temperature of the ageing treatment (Rockwell C49 for the titanium-bearing steel R4500 when aged at 850° F. as compared to Rockwell C38 when aged at 1150° F.).

In the work-hardened and age-hardened condition the steels of my invention possess a combination of high surface hardness together with internal toughness and ductility; the internal hardness is substantially lower than the surface hardness. The hardness of the finished metal is greatest where the greatest cold-working has been had and least where the least amount of cold-working results (compare the figures for 60% reduction and aged with those for the 40% reduction and aged). In every case the final hardness achieved is not that of the cold-working operation, but it is that of the combination of cold-working and age-hardening as may be seen by the increase had with the ageing treatment.

The steel of my invention ordinarily is supplied various customer-fabricators in the form of bar, rod, wire, sheet, strip, special shapes, and the like, either in hot-worked

condition or in the annealed condition. In either condition the metal readily lends itself to various cold-working and cold-forming operations, as in the production of a variety of articles and products wherein a moderate hardening is had. And the cold-worked and cold-formed products then lend themselves to subsequent age-hardening, giving a combination of high surface hardness, abrasion-resistance and wearability, together with internal toughness and ductility. Where desired, however, the steel may be supplied the customer-fabricator in the fully reduced or partially cold-reduced form. Or the steel even may be supplied in cold-reduced and aged condition, for example drastically cold-drawn and aged wire for automobile radio antennae where the customer-fabricator merely is required to taper-grind the wire.

As particularly illustrative, reference is made to the production of self-tapping drive screws, this by way of automatic machinery. In this operation wire stock of sulphur content not exceeding about 0.015% supplied a customer-fabricator is upset in forming a screw head. The head then may be provided with a milled slot or it may be recessed to provide a Phillips head. The required thread is rolled on. In this cold-rolling operation, as well as in the cold-upsetting operation, the extent of the cold-reduction had approaches 60% or more. The resulting hardness comes to some Rockwell C30–36, the higher figure being had with the magnetic screws.

The cold-formed screws are subjected to age-hardening treatment with a resultant increase in hardness approaching Rockwell C53 for the magnetic screws (ageing at 700° to 900° F.) and a hardness approaching C42 for the non-magnetic screws (with ageing at 850° F. to 1250° F.).

The screws in age-hardened condition are possessed of a surprising combination of great surface hardness, particularly at the extreme edges of the threads where a maximum of cold-reduction is had, together with much reduced hardness, and great toughness and ductility, throughout the core. The surface of the sunken head likewise is hard and is admirably adapted to accommodate a driving tool, that is, power screwdriver or manual screwdriver. The threads of high surface hardness are abrasion-resistant and cut into metal siding, sheathing, and the like, as a self-tapping operation. And the screws are well suited to secure metal pieces together, holding them firmly without thread breakage.

Screws of the particular composition balance resulting in an austenitic and non-magnetic structure are peculiarly adapted to the securing of aluminum siding, roofing, and the like, as well as refrigerator, washing-machine and other aluminum housings, in that they are free of the hydrogen-embrittling effect resulting from galvanic action found in certain screws of the prior art, notably those of martensitic structure.

As further illustration, the austenitic, and non-magnetic, steel of my invention also is suited to the production of instrument springs, instrument panels, dials, pointers, and the like, where rigidity and strength are desired. And the magnetic steel, as well as the non-magnetic steel, lending itself to drastic cold-reduction, this on the order of some 65% and more, especially some 80% to 95% or more, is suited to the production of a variety of springs, both domestic and industrial where great hardness is required. The steel is especially suited to the production of radio antennae for automobiles, which antennae are cold-reduced and aged, especially where cold-reductions on the order of 90% and more are contemplated.

CONCLUSION

Thus it will be seen that I provide in my invention a chromium-nickel-copper stainless steel containing titanium in which the various objects hereinbefore set forth, together with many practical advantages, are successfully achieved.

The steel of my invention, by reason of particular chromium-nickel-copper-titanium composition, and a particular balancing of the same, readily lends itself to cold-working and cold-forming, as by drawing, upsetting, rolling, spinning and the like without excessive hardening of the metal. Thereafter, the steel lends itself to great hardening, i.e., hardening by heat-treatment at moderate temperatures to achieve an ageing or precipitation-hardening effect.

Since many embodiments may be made of my invention and since numerous changes may be made in the embodiments hereinbefore set forth, it will be understood that all matter described herein is to be interpreted as illustrative, and not by way of limitation.

I claim as my invention:

1. A precipitation-hardenable titanium-bearing chromium-nickel-copper stainless steel which in the cold-worked and aged condition is substantially magnetic and said steel consisting essentially of 10% to 22% ingredient of the group consisting of chromium and molybdenum, with chromium at least 10% and with molybdenum up to 5% substituted for the chromium on a 1 to 1 basis; 5% to 16% ingredient of the group consisting of nickel and ½ manganese, with nickel at least 4% and manganese up to 12% substituted for nickel on a 2 to 1 basis, with the relation between the chromium plus molybdenum and the nickel plus ½ manganese within the broad ranges being:

Chromium and Molybdenum	Nickel and ½ Manganese
10%	13% to 16%
12%	8% to 14%
16%	7% to 13%
19%	6.5% to 9.5%
22%	5% to 6%

1% to 4% copper; .3% to 4% titanium; and remainder substantially all iron.

2. A precipitation-hardenable titanium-bearing chromium-nickel-copper stainless steel which is essentially non-magnetic and consists essentially of 10% to 25% ingredient of the group consisting of chromium and molybdenum, with chromium at least 10% and molybdenum up to 5% as a substitute for chromium on a 1 to 1 basis; 11% to 20% ingredient of the group consisting of nickel and ½ manganese, with nickel at least 4% and manganese up to 15% substituted for nickel on a 2 to 1 basis, with the relation between the chromium plus molybdenum and nickel plus ½ manganese within the broad ranges noted being:

Chromium and Molybdenum	Nickel and ½ Manganese
10%	15% to 20%
12%	14% to 20%
16%	12% to 20%
19%	11% to 20%
22%	14% to 20%
25%	15% to 20%

1% to 4% copper; 2% to 3% titanium; and remainder ssubstantially all iron.

3. A precipitation-hardenable titanium-bearing chromium-nickel-copper stainless steel which in hardened condition is magnetic, said steel essentially consisting of 12% to 18% chromium, 7% to 11% nickel with the nickel being at least 8% when the sum of the chromium and any molybdenum is 12% and at least 7% when the chromium plus any molybdenum is 16%, 2% to 5% copper, .5% to 2% titanium, and remainder substantially all iron.

4. A precipitation-hardenable titanium-bearing chromium-nickel-copper stainless steel which in hardened condition is non-magnetic, said steel essentially consisting of 15% to 18% chromium, 11% to 15% nickel with the nickel being at least 14% when the chromium plus any molybdenum is 12%, 2% to 5% copper, 2% to 3% titanium, and remainder substantially all iron.

5. A precipitation-hardenable stainless steel essentially consisting of about 14% chromium, about 8% nickel, about 3% copper, about 2% molybdenum, .5% to 2% titanium, and remainder substantially all iron.

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