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PRECIPITATION HARDENED FERROUS ALLOY CONTAINING COPPER

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ABSTRACT OF THE DISCLOSURE

Ferrous base copper alloys are provided consisting essentially of 3.0% to about 8.0% copper, an addition agent in the amount of 0.2% to 1.0% consisting of at least one element of the group of aluminum, silicon, titanium and zirconium, an incidental amount to 1.0% manganese, a trace to 0.1% each of carbon, sulphur, and phosphorus, and the balance iron, and also a method and treated products are provided wherein the alloy composition is solution heat treated and aged to attain a high strength level with retention of ductility.

This application is a continuation-in-part of our copending application Ser. No. 393,756, filed Sept. 1, 1964, now abandoned and the invention relates to alloy compositions, more particularly to age hardenable ferrous base copper alloys as well as to a method for producing the hardened alloys, and to the alloy products both prior to hardening and after hardening.

An object of this invention is the provision of copper alloys having a ferrous base and an alloy content which is appreciably low, the alloys being amenable to age hardening and moreover capable of developing as an incident to the hardening a yield strength and ultimate tensile strength which are remarkably improved.

Another object of the present invention is the provision of alloys of the character indicated which respond favorably to hot working at temperatures within the solution temperature range and retain ductility which is adequate for any of a variety of purposes after being age hardened.

A further object of this invention is that of providing alloys of the character indicated which quite satisfactorily lend themselves to being enhanced in hardness and strength and which exhibit these improvements after an aging heat treatment conducted much below solution temperature.

A still further object of the invention is to provide alloys having a relatively low alloy content and which nevertheless are highly responsive to aging and which produce commensurately an increase in tensile strength.

Other objects of the present invention and advantages of the same will be obvious and in part more fully pointed out during the course of the following disclosures.

The invention therefore 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 clearer understanding of certain features of the present invention various ferrous base alloys in the prior art depend for hardening and enhancement of strength upon a carbon content and the ability to form martensite. Among these alloys are ferrous base alloys taken from existing groups of well known stainless steels and lower alloy steels. The hardening is accomplished by heating to a solubilizing temperature to effect solution of carbon and other alloying elements in

austenite followed by sufficiently rapidly cooling to achieve martensite. There are well known difficulties, however, that are incident to the carbon martensite mode of hardening. For example, any fashioning of the alloys in the relatively soft condition at room temperature prior to hardening must be followed by a high temperature solubilizing treatment, and hardening thereafter is accomplished by quenching. In the foregoing sequence of operational steps, the high temperature at which the solubilizing treatment is maintained demands the prevention of high temperature oxidation and the prevention of warping or of other deviations away from desired form of the alloy product at these high temperatures or when the alloys are being quenched from these temperatures, if an erasure of certain advantageous results of having worked the metal while the metal still was relatively soft is to be avoided.

Other known alloys, including certain of the heretofore known stainless steels, are age hardenable. This mode of hardening involves preliminarily heating the alloy at solution temperature until solid solution is obtained, and following with cooling and aging at a temperature considerably below the solution temperature. Hardness develops from the aging and accordingly one great advantage of certain of the age hardening alloys is that forming or machining operations are practical before aging, and therefore may be availed upon at a time when the alloy is relatively soft after cooling from solution temperature and is without need for being reheated to anywhere approaching this high temperature again for hardening. However, many of the age hardening alloys, such as the particular stainless steels which heretofore have been available for the purpose, are of high alloy content and thus are relatively expensive as compared with ordinary steels, or though having a ferrous base, or a base which is other than ferrous, still lack the asset of high response to aging with or without other supplemental advantages.

An outstanding object of this invention accordingly is the provision of industrially practical ferrous base copper age hardenable alloys which are highly competitive commercially for such reasons as having a relatively low alloy content coupled with quite favorable age hardening response characteristics and worthwhile physical properties before and after the alloys are age hardened.

Referring now more particularly to the practice of the present invention, it is found that by combining proper amounts of iron and copper with a proper quantity of one or more of aluminum, silicon, titanium and zirconium and controlling the alloy composition to maintain small amounts of any other constituents, a ferrous base copper alloy is obtained which very effectively responds to a simple aging treatment at satisfactorily low temperatures and thus increases in strength by an indeed worthwhile extent.

This invention accordingly introduces ferrous base alloys which contain about 3.0% to 8.0% copper, an additive in the amount of approximately 0.2% to about 1.0% with the additive being at least one element of the group consisting of aluminum, silicon and titanium, and the remainder of the alloy substantially all iron except for small supplemental amounts of other tolerable constituents, among these being manganese from incidental amounts up to about 1.0% maximum, and phosphorus, sulphur and carbon each from a trace up to about 0.1% maximum. Zirconium may be present as a substituent in the alloys and, where present, may be anywhere from an amount of zirconium of about 0.2% to 1.0% in substantially full absence of titanium, silicon and aluminum from the alloy, to an amount of zirconium having therewith in the alloy an additive of at least one element of the group con-

sisting of titanium, aluminum and silicon, with the zirconium plus the additive totaling about 0.2% to 1.0%. More generally, therefore, the ferrous base, 3.0% to 8.0% copper alloys herein contain an addition agent in the amount of approximately 0.2% to 1.0% with the addition agent being at least one element of the group consisting of titanium, zirconium, aluminum and silicon. Manganese, tends to maintain hardness of the alloys and counteracts adverse effects of such elements as sulphur, but in replacement of copper detracts from the amount of copper which otherwise would be available to go into solution. The phosphorous, sulphur and carbon are regarded as impurities and, though permissible each up to about 0.1%, preferably are each from a trace up to about 0.04% maximum.

The foregoing quantities of copper and of addition agent of the group consisting of aluminum, titanium, zirconium and silicon, are regarded as being critical to achieving such worthwhile properties in the alloys as acceptable freedom from hot shortness, high aging response, and the retention of worthwhile ductility after aging. These properties, while tending to disappear toward the outside of the aforementioned limits on copper and addition agent from the group consisting of aluminum, titanium, zirconium and silicon, become all the more favorably pronounced in a preferred alloy composition which in accordance with the present invention contains about 4.5% to 7.0% copper, an additive in the amount of approximately 0.3% to 0.75% with the additive being at least one element of the group consisting of aluminum, titanium and silicon, and the remainder substantially all iron except for small amounts of other tolerable constituents, among these being manganese from incidental amounts up to about 1.0% maximum, and phosphorus, sulphur and carbon each from a trace up to about 0.04% maximum. The latter alloys are sometimes modified with respect to the additive by having aluminum, titanium and silicon all substantially fully absent, and replaced by zirconium as a substituent in amount of about 0.3% to 0.75%, or by having the zirconium in the alloy with the additive and the zirconium plus the additive totalling about 0.3% to 0.75%. The preferred ferrous base, 4.5% to 7.0% copper alloys therefore may be further and more generally categorized as those which contain an addition agent in the amount of approximately 0.3% to 0.75% with the addition agent being at least one element of the group consisting of titanium, zirconium, aluminum and silicon.

Any one or more of the alloying additions of aluminum, silicon, titanium and zirconium promote hot working properties and freedom from hot shortness and moreover in the presence of copper share with copper by going into solution at the solution temperatures and ultimately cooperate with this copper so as to produce the age hardening effect and stengthening of the alloys. As the amount of addition agent from the group consisting of aluminum, silicon, titanium and zirconium is decreased to amounts appreciably outside the more general composition limits herein hot shortness is encountered and high response to aging is sacrificed, while an increase in the addition agent appreciably upward from these same limits is conducive to excessive brittleness after age hardening. Substantially smaller amounts of copper outside the more general composition limits referred to promote reduced ductility and lower the aging response, while substantially larger amounts of copper outside these same limits lead to hot shortness.

To harden the present alloys by aging, the alloys first are heated at solution temperature until solid solution saturated with copper and addition agent of at least one of the group consisting of aluminum, silicon, titanium and zirconium is achieved, the heating being in a range of about 1500° F. to about 1850° F. and for a period of time which usually is about one-quarter of an hour to about two hours or more depending upon such factors as the temperature selected and the particular shape and size of the alloy metal body which is being treated. As solution treating temperature is increased in the range the solubility of copper and addition agent from the group consisting of titanium, zirconium, aluminum and silicon commensurately increases with temperature. Accordingly through relying upon a proper solution temperature and the corresponding solubility factor, hardness, yield strength and ultimate tensile strength of the alloys are readily controlled, bearing in mind that hardness and strength of the alloys in the as solutioned and cooled condition, prior to aging, increase with increase in the amounts of copper and addition agent of the group consisting of aluminum, silicon, titanium and zirconium which are then in solid solution. Should carbon be present in the alloys in quantity toward the upper tolerable limit of about 0.1% carbon, the solution temperature is best maintained on the low side in the aforementioned solution temperature range for otherwise the aging response characteristics tend to suffer.

The alloys of the present invention, being amenable to hot rolling and to any of a host of other forms of hot working at elevated temperatures, are so worked as occasion may demand, thus producing any such products as forgings, sheet, strip, tubing, rods, bars, I-beams, channels, rails, or the like. The optimum hot working temperatures fall within the solution temperature range, and are about 1600° F. to about 1800° F. Following the solution heat treating stage, the alloys are quenched preferably to about room temperature in a liquid coolant such as oil or water, or in a gaseous coolant such as air. In accordance with preferred practice the alloys are hot worked, then solution heat treated, and the solution heat treatment is followed by a rapid quench of the heat treated alloys as in oil or water to about room temperature. An appreciably more rapid quench than cooling in air at usual room temperature is preferred, for the amounts of copper and addition agent from the group consisting of aluminum, titanium, zirconium and silicon in solid solution from the solution heat treatment tend to be less effectively retained in solution through slowly cooling the alloy in air. Nevertheless, in practices still in accordance with the present invention, adequately favorable results for certain purposes are had through heating the alloys to hot working temperature and concurrently achieving solution treatment, the solution heat treated alloys then being hot worked and cooled through hot working and in ordinary air or more rapidly until room temperature is reached.

When the alloys within the more general composition limits hereinbefore set forth are in the solution heat treated and quenched condition, they have ductility, and hardness which is considerably short of their full potential on hardness, and accordingly the alloys are usually subjected to forming or fabricating steps at this stage, thereby producing articles and products of the alloys by any one or more such operations as cutting, punching, machining, or the like under the advantage of the then existing favorable properties of the alloys. These operations of course may be performed at room temperature or at other low temperatures which do not materially alter the solution heat treated and quenched condition of the alloys. Thereafter, to harden the alloys, such as the alloy metal in the aforementioned articles and products, the metal is brought up to aging temperature in an aging heat which endures long enough to bring copper and addition agent from the group consisting of aluminum, titanium, zirconium and silicon out of solution and into dispersed fine form throughout the alloy. The heating for aging is conducted at a temperature in the approximate range of 500° F. to 1000° F. for a length of time depending on the particular aging temperature used. Within this approximate range the particular temperature therefore is not extremely critical, though as temperature within the range is increased the corresponding period of aging time is decreased. There is moreover a tolerable

latitude with respect to length of aging time corresponding to the temperature selected, though this latitude diminishes as the temperature within the range is increased. Size and shape of the articles and products also may cause adjustments to be made in length of the aging period; however, average duration of the aging treatment at about 500° F. is usually somewhere in the vicinity of about 25 hours and a like average period of time for aging the alloys at approximately 1000° F. is somewhere about ½ hour. For example, either aging at 700° F. for about 2 to 8 hours or at 900° F. for ½ hour to 2 hours are typical temperature-time relations which are observed. The aging treatment is terminated by bringing the aged alloys down to the environs of room temperature from the aging temperature. This for example is either by air cooling or by more rapidly quenching such as in oil or water.

The alloys with adequate amounts of copper and addition agent of the group consisting of aluminum, silicon, titanium and zirconium in solution are highly responsive to the foregoing aging treatment in the sense that the aged alloys display a yield strength and an ultimate tensile strength enhanced by amounts, each exceeding about 20,000 p.s.i. and sometimes exceeding about 60,000 p.s.i. or more, correspondingly over yield strength and ultimate tensile strength of the alloy in the solutioned and cooled condition before aging. Further, the aged alloys have a ductility, represented by an elongation in two inches, which is upward of at least about 4% and sometimes closely approaching 20% or more. Of further consequence it will be noted that the highly worthwhile properties relating to ductility and enhanced strength through aging add to the fact that the alloys are hot workable in the solution temperature range and display adequate freedom from hot shortness. Certain of the alloys, however, through having been treated for solubilizing at temperatures which are relatively high within the hereinbefore described more general range of solution heat treating temperatures may, because of the foregoing relatively high treating temperature as an attribute, be characterized by more than a tolerable loss of ductility through aging if ductility which is upward of at least about 4% on 2-inch elongation after aging is to be retained, and to remedy this situation those alloys are best solution heat treated at the lower solubilizing temperatures within the more general range and then are cooled and aged through the re-heat as hereinbefore set forth. Retention of ductility through aging or thus exceeding any particular minimum on ductility, though, is of course not always an essential objective, the other properties of the aged alloys, including remarkably increased strength brought about by the aging, being quite adequate sometimes for the alloys to serve specialized needs.

An open hearth furnace is often utilized for producing the present alloys in order to meet large tonnage demands, though other furnacing equipment instead is also satisfactory, as for example an electric arc furnace especially where smaller tonnage production is to be accomplished. For maintaining carbon level within the limits desired in the alloy, an oxygen process is found to be advantageous particularly if high-carbon charging stock is used and thus initially introduces very considerable quantities of carbon in the melt. Thus, for example, if need be the electric arc furnace process is adapted to an oxy-process for adjusting the carbon content to within tolerable amounts as by use of an oxygen lance during refining.

As illustrative of a production technique employed, a Herault type direct-arc furnace of about 50,000 pound rated capacity and having a basic lining is employed. Usually an initial charge of somewhere in the general vicinity of 40,000 pounds is introduced in the furnace, electrolytic copper for example being present in amount of about 2,280 pounds and there additionally being about 37,340 pounds of low-carbon, low alloy steel scrap with sufficient iron ore to reduce the carbon content appreciably during carbon boil. If the alloy content of the steel scrap is relatively high, the quantity of steel scrap in the charge is diminished in favor of adding ingot iron in replacement of the scrap. The amount of iron ore present is varied and depends upon such factors as the initial carbon content of the scrap and the characteristics of the particular furnace used. Upon completion of the initial charging, the arcs of the furnace are struck and melting of that portion of the charge next to the electrodes is promoted under relatively lower power. After a pool of molten metal is obtained near the electrodes, the power then is increased to accomplish very rapid melt down of the charge. During melt down and during a period immediately following melt down, oxidation of the carbon and other reactive alloying elements occurs. In order to prevent "phosphorus reversion" during the oxidation or refining period, it is helpful to make additions of CaO, which material maintains a basic slag over the melt. The copper charge is largely unaffected by the bath reactions, and virtually no copper loss is to be expected. This is notable in taking first samples for analysis, though mainly the analysis is made to determine carbon, manganese and "oxidizible elements" contents.

The refining process sometimes is carried out as a double slagging operation, in which event the slag without any initial additions of CaO is first allowed to become oxidizing, and then the furnace power is turned off, the electrodes raised, and the slag is thoroughly raked out. Thereafter, another charge is made, this consisting of about 5 parts CaO, 1 part fluorspar, and 1 part sand, which becomes the second slag and of course is basic. If the sulphur content is found to be above say about 0.04 an addition of ferromanganese is advantageously made to tie up sulphur as manganese sulfide. The electrodes are lowered, the power turned to a high setting for rapid reheating and a short refining period at high temperature of about 2900° F. to 3000° F. ensues. At this point a second sample is taken for analysis, mainly to determine whether carbon, sulphur and phosphorus contents are within tolerable limits. A satisfactory determination in this respect is followed by making final additions. For an alloy in which a silicon content of about 0.4% and an aluminum content of about 0.3% are for example desired, the melt is first deoxidized preferably with approximately 100 pounds of high-purity aluminum, and then about 208 pounds of low-carbon ferrosilicon (76% Si) and 120 pounds more of high-purity aluminum are added. Within about 10 minutes from making these additions, the furnace is tapped into the ladle and during tapping still another 100 pounds of high purity aluminum is added, this to the metal stream for final deoxidation, and to adjust the desired aluminum content. This total charge in the furnace thus illustratively yields an alloy containing about 5.7% copper, 0.4% silicon, 0.3% aluminum, 92.6% iron, and other tolerable elements up to about 1% total, among which are carbon, phosphorus and sulphur each not exceeding about 0.04% and the remainder mainly being manganese, chromium and nickel from the steel scrap of the charge. About 200 pounds of aluminum are added for purposes of deoxidation. The ladle is next moved into pouring position, and the melt is introduced into molds which in size and shape may depend upon the particular product which is to be produced from the ingot.

As further illustrative of the practice of this invention an electric induction furnace having a magnesia crucible is charged with ingot iron having a low enough carbon content in view of any other carbon additions for the charge to yield a melt containing about 0.01% carbon. Electrolytic copper in proper amounts is also charged into the induction furnace, this being followed by a melt-down under air. On completion of this operation the melt is deoxidized as for example with calcium-manganese-silicon or with aluminum, the aluminum being

preferred. After deoxidation has been completed, the melt is finally adjusted in alloy content, at which time an addition is made from the group consisting of aluminum, titanium, zirconium and silicon. Should aluminum be desired either or both for deoxidizing or as a further additive this conveniently takes the form of the pure metal. Where one or more of silicon, titanium and zirconium are to be used from the group they may for example be of low carbon ferroalloys thus added to the melt. Carbon is neither necessary nor desirable in the age hardenable alloys being produced in the furnace, though it occurs but within tolerable limits as a contaminant such as through having in certain instances high carbon pig iron present in the charge not to exceed about 0.1% carbon finally in the melt. The finally adjusted melt is cast into billet form, the cast metal thereafter being allowed to cool and solidify as billets.

Continuing still further by way of illustration, a variety of billets were produced each having a different alloy composition within the general ranges set forth herein, this by providing corresponding melts and casting in the manner just described. Test results based on various ensuing treatments in keeping with the practice of this invention are indicated in Table I. Billets of all of the alloys noted were hot rolled producing strip at temperature of about 1600° F. to 1800° F. and samples eventually were cut from the strips for test purposes. It will be understood that the carbon content of all of the tabulated alloys is about 0.01% except for alloy G, wherein the carbon content is substantially 0.1%. Some few of the alloys were hot worked beginning at temperatures within the solution temperature range without any further solution heat treatment prior to cooling in air to room temperature. In the main, however, the tabulated alloys were given solution heat treatments at the temperatures and for the periods of time indicated and then were immediately quenched from the solution temperature to room temperature. Also it will be seen that aging treatments were then applied, this through heating alloys as solutioned and quenched up to the given aging temperatures by aging for any of a variety of aging periods of time. The hardness values noted are respectively those of the alloys in the as solutioned and cooled pre-aged condition and in the aged condition. In most instances yield strengths and ultimate tensile strengths are indicated correspondingly for the as solutioned quenched alloy and for the alloy after the aging heat treatment. In some cases, though, these values on strength have been omitted with reliance upon the hardness values before and after aging as being indicative.

TABLE I

Alloy Composition	Solution Heat Treatment	As-solutioned hardness, Rockwell	Aging treatment, ° F.	Aged hardness, Rockwell	0.2% offset yld. str., p.s.i.	Ultimate tens. str., p.s.i.	Elong. in 2 in., percent
Alloy:							
A—5.7% Cu, 0.25% Al [1]	1,650° F.-½ hr., water quenched	B90	900/3 hr.	C28			
	1,650° F.-1 hr., water quenched	B96			77,900	84,800	6
			900/2 hr.	B102	101,100	109,200	14
	1,750° F.-½ hr., water quenched	B100	900/2 hr.	C32			
	do	B100			87,000	97,000	9
			900/1 hr.	C34	139,000	147,000	13
	1,850° F.-½ hr., water quenched	C25	900/1 hr.	C38			
	do	C25			100,000	112,300	10.5
			900/1 hr.	C38	157,800	161,300	11.3
B—7.2% Cu, 0.33% Al [1]	1,650° F.-½ hr., water quenched	B94			88,800	95,400	9.3
			900/1 hr.	C30			
			900/2 hr.	C31	122,500	129,000	12.5
	1,750° F.-½ hr., water quenched	C24	900/1 hr.	C34			
			900/2 hr.	C33			
	1,850° F.-½ hr., water quenched	C30	900/1 hr.	C38			
C—7.0% Cu, 0.89% Al [1]	1,650° F.-½ hr., water quenched	B82			61,300	67,600	17
			900/2 hr.	C27	110,800	115,500	15.5
	1,650° F.-½ hr., water quenched	B87-89			67,200	86,125	14.5
			900/2 hr.	C28	120,750	131,500	12
D—6.8% Cu, 0.72% Ti [1]	1,750° F.-½ hr., water quenched	B95			83,400	97,300	9
			900/1 hr.	C36			
			900/2 hr.	C36	147,000	153,000	8
			800/6 hr.	C37	139,300	145,300	7
E—5.75% Cu, 0.89% Ti [1]	1,650° F.-½ hr., water quenched	B85	900/2 hr.	C24			
	1,650° F.-½ hr., air cooled	B85	900/2 hr.	C25			
	1,650° F.-½ hr., water quenched	B97			81,300	89,700	19
	do		900/2 hr.	C32	129,500	134,000	13
F—6.40% Cu, 0.75% Si [1]	1,750° F.-½ hr., water quenched	C20			96,200	106,000	16
	do		900/2 hr.	C34	142,500	147,000	12
	1,850° F.-½ hr., water quenched	C23			105,000	116,000	7
	do		900/2 hr.	C36	152,500	156,000	10.5
	1,550° F.-1 hr., water quenched	B91			69,800	93,300	15
			900/2 hr.	C25	116,500	119,000	9
G—6.7% Cu, 0.10%, C, 0.55% Al [2]	1,550° F.-1 hr., air cooled	B94	900/1 hr.	C25			
	1,650° F.-½ hr., water quenched	C21			88,600	115,300	7.5
			900/1 hr.	C34			
			900/2 hr.	C34	128,000	131,500	4.5
H—3.30% Cu, 0.22% Al [1]	1,850° F.-½ hr., water quenched	B72			50,700	59,200	17.5
			900/2 hr.	C23	89,800	94,500	7
	1,650° F.-½ hr., water quenched	B82-86			65,600	77,800	15
			900/2 hr.	C26	118,000	121,500	8
	1,650° F.-½ hr., air cooled	B93	900/1 hr.	C22			
			900/2 hr.	C24			
I—6.1% Cu, 0.46% Al, 0.27% Si [1]	1,750° F.-½ hr., water quenched	C19			91,000	99,600	10
			700/8 hr.	C37	118,500	129,000	11
	1,850° F.-½ hr., water quenched	C22-24			103,500	109,000	4.5
			900/1 hr.	C36-39	154,000	160,000	4.5
			900/2 hr.	C34-39			
J—6.55% Cu, 0.46% Si, 0.24% Ti [1]	1,650° F.-½ hr., water quenched	B92			67,200	84,300	17
	do		900/2 hr.	C32	121,000	132,300	12.5
K—6.05% Cu, 0.23% Al, 0.18% Ti [1]	1,650° F.-½ hr., water quenched	B92			65,700	85,500	16.5
	do		900/2 hr.	C32	122,000	131,500	9.5
L—5.60% Cu, 0.30% Al [1]	1,650° F.-½ hr., water quenched	B93			85,500	93,500	10.5
	do		900/2 hr.	C30	123,000	131,300	11
M—5.4% Cu, 0.33% Zr [1]	1,650° F.-½ hr., water quenched	B87			62,250	79,500	11.5
	do	B87	900/2 hr.	C32	117,750	128,750	8.0
N—6.10% Cu, 0.27% Si, 0.29% Zr [1]	1,650° F.-½ hr., water quenched	B89					
	do	B89	900/2 hr.	C33			
O—5.75% Cu, 0.57% Ti, 0.25% Zr [1]	1,650° F.-½ hr., water quenched	B91			68,300	80,300	13.5
	do	B91	900/2 hr.	C33	128,800	137,500	10.
P—6.35% Cu, 0.32% Al, 0.24% Zr [1]	1,650° F.-½ hr., water quenched	B85			59,500	75,700	10.5
	do	B85	900/2 hr.	C31	109,500	120,000	9.0

[1] And Mn less than about 1% maximum, C about 0.01%, S and P each less than about 0.04% maximum, remainder substantially all iron.
[2] And Mn less than about 1% maximum, C about 0.1%, S and P each less than about 0.04% maximum, remainder substantially all iron.

It will be observed from the preceding tabulated data that hardness values are increased through aging and that the increases in yield strength and ultimate tensile strength are extraordinarily large as a highly important result of aging. Ductility of the aged alloys, moreover, comes to within a thoroughly acceptable range, this remembering too that each of the alloys represented was satisfactorily hot worked prior to being water quenched or air cooled to be in readiness for the aging treatment.

Accordingly it will be appreciated that in the present invention ferrous base copper alloys and a method are provided wherein the various objects noted together with many thoroughly practical advantages are successfully achieved. The alloys are in fact of relatively low alloy content and yet offer such important advantages as being capable of being remarkably enhanced in yield strength and ultimate tensile strength through being solution heat treated and then aged at temperatures which sensibly are far below solution temperatures, and further it will be appreciated that prior to being aged the alloys are hot workable by rolling, forging, or the like, and indeed are workable and capable of being fabricated at or near room temperatures, with a view toward the resulting articles and products subsequently being hardened by heating at aging temperatures if the intended purpose of the products and articles so demands that strength thus is to be enhanced. The alloys held at aging temperature for strength enhancement and hardening, accordingly, are at relatively mild temperature as compared with solution temperatures, and so products and articles which are produced from the as solutioned alloys by such steps as those which include cold working and fabricating are on many occasions types which are spared a re-heat to the more rigorous solution temperature and a re-cooling prior to being aged.

Inasmuch as many embodiments may be made of this invention, and as many changes and modifications may be made of the disclosed embodiments, it will distinctly be understood that the foregoing disclosure is to be considered as illustrative, and not as a limitation.

We claim:

1. A ferrous base copper alloy consisting essentially of 3.0% to 8.0% copper, an addition agent in the amount of 0.2% to 1.0% consisting of at least one element of the group of aluminum, silicon, titanium and zirconium, an incidental amount to 1.0% manganese, a trace to 0.1% each of carbon, sulfur and phosphorus, and the balance iron, said alloy being in a precipitation hardened condition, thus having been solution heat treated for a period of time of at least about ¼-hour to 2 hours within the approximate temperature range of 1500° F. to 1850° F., with said temperature substantially low in said range for at least said alloy having carbon most proximate to 0.1%, and said solution heat treated alloy aged within the approximate temperature range of 500° F. to 1000° F. for a period of time consistent with average duration of said aging period being a variable in inverse order with temperature from about ½-hour for the highest temperature in said aging temperature range to about 25 hours for the lowest temperature in said aging temperature range.

2. A precipitation hardened ferrous base copper alloy of claim **1**, characterized by having said addition agent in the amount of 0.2% to 1.0% consist of silicon and at least one element of the group of aluminum, titanium and zirconium.

3. A precipitation hardened ferrous base copper alloy of claim **1**, characterized by said carbon being from a trace to an amount more proximate to 0.04% than to 0.1%.

4. A precipitation hardened ferrous base copper alloy of claim **1**, characterized wherein the amount of said addition agent is 0.30% to 0.75%.

5. A precipitation hardened ferrous base copper alloy of claim **4**, characterized by said copper being 4.5% to 7.0%.

6. A precipitation hardened ferrous base copper alloy of claim **1**, characterized by said copper being at least 4.5%.

7. A precipitation hardened ferrous base copper alloy of claim **1**, characterized by said carbon being from a trace to substantially 0.04% maximum.

8. A precipitation hardened ferrous base copper alloy of claim **2**, characterized by said copper being 4.5% to 7.0% and said addition agent being in amount of 0.30% to 0.75%.

9. A ferrous base copper alloy consisting essentially of 3.0% to 8.0% copper, an addition agent in the amount of 0.2% to 1.0% consisting of at least one element of the group of aluminum, silicon and titanium, an incidental amount to 1.0% magnanese, a trace to 0.1% each of carbon, sulfur and phosphorus and the balance iron, said alloy being in a precipitation hardened condition, thus having been solution heat treated for a period of time of at least about ¼-hour to 2 hours within the approximate temperature range of 1500° F. to 1850° F., with said temperature substantially low in said range for at least said alloy having carbon most proximate to 0.1%, and said solution heat treated alloy aged within the approximate temperature range of 500° F. to 1000° F. for a period of time consistent with average duration of said aging period being a variable in inverse order with temperature from about ½-hour for the highest temperature in said aging temperature range to about 25 hours for the lowest temperature in said aging temperature range.

10. A precipitation hardened ferrous base copper alloy of claim **9**, characterized by having said addition agent in amount of 0.2% to 1.0% consist of silicon and at least one element of the group of aluminum and titanium.

11. A precipitation hardened ferrous base copper alloy of claim **9**, characterized by said carbon being from a trace to an amount more proximate to 0.04% than to 0.1%.

12. A precipitation hardened ferrous base copper alloy of claim **11**, characterized by said copper being 4.5% to 7.0% and said agent being 0.30% to 0.75%.

13. A precipitation hardened ferrous base copper alloy of claim **9**, characterized by said carbon being from a trace to substantially 0.04% maximum.

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