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PRECIPITATION HARDENABLE, CORROSION RESISTANT, CHROMIUM-NICKEL STAINLESS STEEL ALLOY

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This invention relates to stainless steel alloys, and more particularly to a precipitation hardenable, corrosion resistant, chromium-nickel stainless steel alloy.

A most popular stainless steel alloy is a high chromium-nickel steel, especially the so-called 18–8 stainless steel. In general, this stainless steel is not hardenable, but was found to be hardenable by the addition of a substantial quantity of beryllium, which is costly. In my Patent 2,635,044, issued April 14, 1953, and entitled "Hardenable Stainless Steel Alloy," I disclosed such an alloy which is precipitation hardenable while requiring the addition of only a very small percentage of beryllium.

The primary object of the present invention is to generally improve stainless steel alloys. A more particular object is to provide a precipitation hardenable stainless steel alloy which does not require the addition of beryllium and which may be made at relatively low cost. The alloy is desirable in situations in which precipitation hardening is wanted, to a very high degree, while not requiring high ductility, and tensile strength.

The new alloy is based on the addition of molybdenum and silicon and copper. It has been found, when galling is not a problem, but great resistance to abrasion is necessary, that beryllium is unnecessary and even detrimental to best results. Best hardness for high abrasion resistance is found by using as high a percentage of silicon, copper and molybdenum as will allow casting without cracking.

The molybdenum is used in a range of from 3 to 5%, and more preferably 3.75–4.25%; silicon is used in a range of 2.5 to 4%, and more preferably 3.25 to 3.75%; and copper is used in a range of from 2.5 to 4%, and more preferably 2.75 to 3.25%.

A specific example of my improved alloy, with its resulting hardness and physical properties and corrosion resistance, are given in the following table as alloy X–20. The chemical analysis is given in percentage by weight.

Table I

Test #	X–18	V–4	X–13	X–20
C.....percent	.033	.063	.044	.032
Cr.....do	20.25	18.02	19.82	20.40
Ni.....do	8.90	8.94	9.32	8.95
Mn.....do	.86	1.02	.71	.79
Mo.....do	3.96	2.34	5.00	4.26
Si.....do	3.46	3.84	1.40	3.46
Cu.....do		3.52	3.68	2.96
BHN:				
WQ	262	241	226	285
PH	341	277	293	415
Physical Properties:				
TS	139,250	110,000	138,847	185,400
YS	105,500	91,900	105,163	150,000
El	8	4.5	21	2
RA	5.5	4	18.1	1.5
Corrosion Tests:				
65% HNO_3 @ Boiling	.0134	.0183	.110	.0141
50% H_2SO_4 @ 80° F	.00009	.00016	.00000	.00000
5% HCl @ 80° F	.0203	.00408	.00000	.017

In the foregoing and succeeding tables, "BHN" means Brinell hardness number; "WQ" means water quenched; and "PH" means precipitation hardened after water quenching. Considered more specifically, the heat treatment consisted of heating the metal at 2000° F. for one hour, followed by water quenching, after which the water quenched sample was held for eight hours at a temperature of 925° F. and then air cooled or furnace cooled for the precipitation hardening.

In the above table "TS" refers to the tensile strength of a specimen in pounds per square inch. "YS" means the yield strength in pounds per square inch at the customary 0.2% offset, that is, departure from proportionality to show that the elastic limit has been exceeded. "El" refers to the elongation of the specimen in percentage, before rupture. "RA" refers to the reduction of area in percentage at the time of rupture.

The decimal figures given in the above table for the corrosion tests are "I. P. M." figures, meaning the corrosion rate in inches of penetration per month when immersed in the indicated acid.

Alloy X–18 in the above table illustrates hardening by the addition of high molybdenum and high silicon without copper. Alloy V–4 has copper, but reduced molybdenum. Alloy X–13 has the amount of silicon greatly reduced. Alloy X–20 illustrates the invention, and shows hardening by the addition of high molybdenum, high silicon, and copper. It should be noted that this X–20 alloy, although showing good figures for yield strength and tensile strength, has only small ductility, that is, the percent elongation figure is only 2%. However, it has very great hardness increase, and therefore this alloy must be considered one which is desirable for very high hardness with only low ductility, compared to X–18, V–4 and X–13.

Additional examples are given in the following Table II:

Table II

Test #	X–46	X–26	X–24	X–14
C.....percent	.038	.034	.040	.046
Cr.....do	19.80	20.00	22.30	19.37
Ni.....do	8.45	9.05	9.45	8.72
Mn.....do	.84	.79	.78	.72
Mo.....do	3.79	5.00	4.33	5.00
Si.....do	3.58	3.20	3.16	4.00
Cu.....do	2.86	2.96	2.88	2.88
BHN:				
WQ	293	302	331	408
PH	415	461	477	601

Both molybdenum and silicon must be used, and either will not alone serve.

Increasing the molybdenum content to say 5% increases hardness. When the molybdenum content is greatly increased to say 6.50% the precipitation hardening rises only a little. A molybdenum content over say 5 or 6% produces very little increase in precipitation hardening effect.

Alloys requiring large quantities of molybdenum, say more than 5%, would probably be undesirable commercially because of high cost. While molybdenum is expensive, it is only moderate in cost compared to beryllium, which is not required at all in any of the alloys disclosed in this specification.

The effect of increasing the silicon content, up to say 4%, is to increase hardness. When the silicon was further increased there was a resulting gain in hardness but it was found that the specimen cracked badly, thus showing that a practical limit for the silicon content is about 4%.

The effect of the addition of copper is illustrated in the following table:

Table III

Test #	X-42	X-28
C percent	.025	.034
Cr do	19.88	20.45
Ni do	9.30	9.14
Mn do	.80	.73
Mo do	----	3.96
Si do	3.32	2.80
Cu do	2.88	2.96
BHN:		
WQ	167	269
PH	179	341

Alloy X–42 shows that the addition of copper and silicon in the absence of molybdenum will not induce precipitation hardening even with a high silicon content. Alloy X–28 shows that when the copper is maintained at a constant level an increase in molybdenum and silicon produces an increase in hardness.

The effect of a change in amount of copper is shown in the following table:

Table IV

Test #	X-19	X-20	X-17	X-14
C percent	.030	.032	.040	.046
Cr do	19.80	20.40	19.75	19.37
Ni do	8.85	8.95	8.95	8.72
Mn do	.85	.79	.72	.72
Mo do	4.10	4.26	4.06	5.00
Si do	3.67	3.46	3.30	2.88
Cu do	2.04	2.96	4.00	4.00
BHN:				
WQ	262	285	269	408
PH	363	415	363	601

Alloys X–19 and X–20 are substantially alike except for an increase in copper from 2.04 to 2.96%. It will be noted that this leads to an increase in hardness by precipitation hardening, from 363 to 415. In these alloys the molybdenum and silicon percentages were at desirable amounts. Alloy X–17 shows a further increase in copper to a value of 4%, and the hardness has fallen off, thus showing that a value of 4% of copper would be about the maximum percentage that could be tolerated. In alloy X–14 the molybdenum has been increased from about 4 to 5%, and the precipitation hardening has increased to a value of 601. The big increase in hardness here shown represents a useful alloy where hardness is of primary importance despite reduction in ductility.

It may be explained that the increase to 3% copper in alloy X–20 was beneficial, and that the increase to 4% copper in alloy X–14 was beneficial, but with an accompanying increase of molybdenum from 4% to 5%. When the copper was increased from 3% to 4% in alloy X–17, while keeping the molybdenum down to 4%, the increase in copper was not beneficial.

The effect of increasing the chromium content is considered in the following table:

Table V

Test #	X-23	X-24
C percent	.040	.040
Cr do	18.10	22.30
Ni do	9.22	9.45
Mn do	.82	.78
Mo do	4.26	4.33
Si do	3.04	3.16
Cu do	2.88	2.88
BHN:		
WQ	241	293
PH	331	415

In alloy X–24 (compared to X–23) the chromium content has been raised from about 18 to 22% and the BHN hardness has increased 84 points. This shows that an increase in the percentage of chromium produces an increase in the precipitation hardening of these silicon, molybdenum, copper alloys.

In Table V it will be seen that I increased chromium from 18 to over 22%. It was unnecessary to carry this increase further because it is well known in this work that increased chromium ordinarily increases hardness, and the experiments in Table V were sufficient to show that this general property applies also to the present alloys. It is also well known in this art that it is not practical to carry the increase of chromium above 30%, and it is for that reason that I consider the useable range of chromium to extend up to 30%.

The effect of increasing the amount of nickel is considered in the following table:

Table VI

Test #	X-46	X-48
C percent	.038	.030
Cr do	19.80	19.85
Ni do	8.45	12.00
Mn do	.84	.85
Mo do	3.79	3.64
Si do	3.58	3.60
Cu do	2.86	2.82
BHN:		
WQ	293	229
PH	415	277

In alloy X–48 the nickel content has been increased from 8.45 to 12%, and the hardness has decreased by 138 points. This shows that increasing the nickel in an alloy of this type reduces the precipitation hardening effect.

In all of the foregoing analyses, the iron content is not included, but it is, of course, understood that the balance is iron, subject to the presence of small amounts of impurities incidental to the usual melting practices when dealing with ferrous metals. To cover this situation I may state that in addition to the elements named in the analyses, the remainder is substantially all iron.

The maximum carbon content should be no higher than, say, 0.08%.

It will be understood that the alloys are fully resistant to salt spray. Indeed, the acid tests shown in Table I are much more severe than a salt spray test.

The alloys are weldable by using welding rods of the same general composition as the alloy being welded.

The results of the foregoing tables of tests may be summarized with the percentages rounded off as follows. The desired result may be obtained by the addition of molybdenum in a range of from 3 to 5%, silicon in a range of 2.5 to 4%; copper in a range of from 2.5 to 4%. I have further found that increasing the amount of chromium produces an increase in hardness and that the reverse is true for nickel, that is, an increase in nickel decreases hardness. In general, when dealing with the alloys described in this specification, the yield and tensile strengths increase with the hardness, although not necessarily in linear proportion.

The present application is a continuation-in-part, and largely a division of my copending but since abandoned parent application Serial No. 490,698, filed February 25, 1955, and entitled "Precipitation Hardenable, Corrosion Resistant, Chromium Nickel Stainless Steel Alloy." That application disclosed what is referred to commercially by the assignee of these applications as its "PH–55" series of alloys, divisible into three alloys designated as "PH–55A," "PH–55B," and "PH–55C."

The PH–55A alloy is characterized by high strength and high hardness with fair ductility, and is intended for erosion and abrasion resistance or for stressed parts in corrosive applications. It is an alloy which answers an objective decided upon by the stainless steel casting industry, expressing the need for a comparatively hard stainless steel alloy having a fair amount of ductility for corrosion-erosion resistance with a minimum of 5% elongation, at 350 BHN hardness. The corrosion resistance was desired to be about equal to that of a CF–8M alloy of the Alloy Casting Institute or A. C. I

(which has 0.08% carbon maximum, 18% chromium, 8% nickel, and 3% molybdenum).

The PH–55B alloy is a ductile alloy characterized by high strength and medium hardness, and intended for shock resistance and high stresses in corrosive applications. It answers an industry-decided objective expressing the need for a high strength ductile stainless steel alloy for structural purposes, with a tensile strength as near as possible to twice that of a cast alloy of the A. C. I. known as CF–8 (which has 0.08% maximum carbon, 18% chromium, and 8% nickel, and a tensile strength of 77,000 p. s. i. average). In this industry-objective the yield strength was to be over 100,000 p. s. i., the elongation was to be over 10%, and the corrosion resistance was to be as good as that of the CF–8. High hardness was not too important.

The PH–55C alloy is characterized by very high hardness and low ductility for use in non-stressed, corrosion resisting parts. It answers an industry-decided objective expressing the need for an extremely hard stainless steel alloy having high abrasion resistance, and not requiring ductility. It is for parts not subjected to shock or strain.

The present application is directed to the PH–55C alloy. The PH–55A and PH–55B alloys are disclosed in companion applications Serial Nos. 564,350 and 564,352 which, like the present application, have been divided from my aforesaid parent application Serial No. 490,698, but which technically may be considered to be continuations-in-part rather than true divisional applications, because of added examples.

A broad range of composition which will effectuate the invention is as follows:

	Percent
C	Under .08
Cr	19–30
Ni	8–10
Mo	3–5
Si	2.5–4
Cu	2.5–4

The preferred range is narrower than the broad range given above, and a preferred or narrowed range may be given as follows:

	Percent
C	Under 0.08
Cr	19.5–20
Ni	9–10
Mo	3.75–4.25
Si	3.25–3.75
Cu	2.75–3.25

Still more preferably the carbon content is kept under 0.05%. The chromium may range up to 20.5% as well as 20%, and the nickel may range down to 8.5% as well as 9%.

It is believed that the composition and behavior of my improved hardenable stainless steel alloy, as well as the advantages thereof, will be apparent from the foregoing detailed description. The new alloy is low in cost and high in corrosion resistance. It is soft enough in the quench annealed condition to be machinable, and may be precipitation hardened by a comparatively low temperature heat treatment. The alloy is resistant to salt spray and acids. The alloy has the high chromium and nickel content of a regular 18–8 type of stainless steel, and therefore retains the advantages of that type of stainless steel.

It will be apparent that while I have set forth specific examples of my improved alloy, changes may be made without departing from the scope of the invention, as sought to be defined in the following claims. In the claims the term "non-stressed parts" is not intended to mean zero stress. It is intended to mean parts not subjected to shock or strain, as those terms are commonly understood in this industry. It means a tensile load so low that ductility is not an important consideration.

I claim:

1. A low cost precipitation hardenable alloy of very high hardness and very high abrasion resistance for use in non-stressed parts not requiring ductility, said alloy consisting essentially of a chromium-nickel stainless steel of the type known generally as 18 and 8, having added thereto molybdenum, silicon and copper, the molybdenum ranging from 3% to 5.0%, the silicon ranging from 2.5% to 4%, and the copper ranging from 2.5 to 4%, the carbon content being less than 0.08%, said alloy being free of beryllium, the said alloy being adapted to be precipitation hardened to a very high degree of hardness by a comparatively low temperature heat treatment.

2. A low cost precipitation hardenable alloy of very high hardness and very high abrasion resistance for use in non-stressed parts not requiring ductility, said alloy consisting essentially of a chromium-nickel stainless steel of the type known generally as 18 and 8, having added thereto molybdenum, silicon and copper, the molybdenum ranging from 3.75% to 4.25%, the silicon ranging from 3.25% to 3.75%, and the copper ranging from 2.75% to 3.25%, the carbon content being less than 0.08%, said alloy being free of beryllium, the said alloy being adapted to be precipitation hardened to a very high degree of hardness by a comparatively low temperature heat treatment.

3. A precipitation hardenable alloy of the general type known as 18 and 8 stainless steel, said alloy having a range of from 19% to 30% chromium and 8% to 10% nickel, said alloy having added thereto molybdenum in a range of from 3% to 5.0%, silicon in a range of from 2.5% to 4%, and copper in a range of from 2.5 to 4%, the remainder being essentially iron with a carbon content not exceeding about 0.08%, said alloy being free of beryllium, and being adapted to be precipitation hardened to a very high degree of hardness by a comparatively low temperature heat treatment.

4. A precipitation hardenable alloy of the general type known as 18 and 8 stainless steel, said alloy having a range of from 19.5% to 20.5% chromium and 8.5% to 10% nickel, said alloy having added thereto molybdenum in a range of from 3.75% to 4.25%, silicon in a range of from 3.25% to 3.75%, and copper in a range of from 2.75% to 3.25%, the remainder being essentially iron with a carbon content not exceeding about 0.08%, said alloy being free of beryllium, and being adapted to be precipitation hardened to a very high degree of hardness by a comparatively low temperature heat treatment.

5. A precipitation hardenable alloy having approximately the following chemical analysis: carbon 0.032%; chromimum 20.40%, nickel 8.95%; manganese 0.79%; molybdenum 4.26%; silicon 3.46%; copper 2.96%; and the balance of the alloy being substantially all iron, the said alloy when hardened being characterized by very high hardness and abrasion resistance for use in parts not requiring ductility.

6. A precipitation hardenable alloy having approximately the following chemical analysis: carbon 0.038%; chromium 19.80%; nickel 8.45%; manganese 0.84%; molybdenum 3.79%; silicon 3.58%; copper 2.86%; and the balance of the alloy being substantially all iron, the said alloy when hardened being characterized by very high hardness and abrasion resistance for use in parts not requiring ductility.

7. A precipitation hardenable alloy having approximately the following chemical analysis: carbon 0.034%; chromium 20%; nickel 9.05; manganese 0.79%; molybdenum 5.00%; silicon 3.20%; copper 2.96%; and the balance of the alloy being substantially all iron, the said alloy when hardened being characterized by very high hardness and abrasion resistance for use in parts not requiring ductility.

8. A precipitation hardenable alloy having approximately the following chemical analysis: carbon 0.040%;

chromium 22.30%; nickel 9.45%; manganese 0.78%; molybdenum 4.33%; silicon 3.16%; copper 2.88%; and the balance of the alloy being substantially all iron, the said alloy when hardened being characterized by very high hardness and abrasion resistance for use in parts not requiring ductility.

9. A precipitation hardenable alloy having approximately the following chemical analysis: carbon 0.046%; chromium 19.37%; nickel 8.72%; manganese 0.72%; molybdenum 5%; silicon 4%; copper 2.88%; and the balance of the alloy being substantially all iron, the said alloy when hardened being characterized by very high hardness and abrasion resistance for use in parts not requiring ductility.

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