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NICKEL-FREE AUSTENITIC ELEVATED TEMPERATURE ALLOY

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This invention relates to austenitic iron base nickel-free alloys suitable for use at elevated temperatures of up to about 1500° F.

Heretofore, most of the austenitic alloys which were used in elevated temperature operations had an economically useful life only if the temperature did not exceed about 1200° F. Some austenitic iron base alloys were usable at higher temperatures, but these alloys contained, in addition to critically strategic alloying elements, a great percentage of nickel, usually in amounts of about 7% or more. The use of nickel was costly and it too is often classified as being critically strategic.

Moreover, with the advent of the so-called "jet age" and the use of turbines, jet engines, rockets, and other forms of propulsion, designers have been continuously changing the design of the power plants to utilize higher temperatures of operation in order to obtain greater efficiency in the operation. This has in turn placed a great burden upon the metal industry to meet the demand of the requisite metals therefor. Where cost and availability are unimportant, known alloys could suffice. However, these sources are not unlimited.

In order to alleviate this condition, the ingenuity of the metal industries' engineers has been summoned in order to develop an alloy which can maintain great strength at elevated temperatures yet be free from relatively costly and strategic alloying elements. In addition, it is also necessary for the alloy to possess sufficient oxidation and corrosion resistance as well as maintain dimensional stability throughout its intended temperature range of operation. This necessitates a substantially single-phased alloy.

An object of this invention is to provide an austenitic iron base nickel-free alloy which is suitable for use at elevated temperatures of up to about 1500° F.

Another object of this invention is to provide an austenitic iron base nickel-free alloy having superior strength and freedom from phase transformations at temperatures of up to at least 1500° F.

A more specific object of this invention is to provide an austenitic iron base nickel-free alloy containing carbon, manganese, chromium, molybdenum, vanadium, nitrogen, columbium, tantalum and copper which is suitable for use at elevated temperatures of up to about 1500° F.

Other objects will become apparent when taken in conjunction with the following description.

In its broader aspects, this invention contemplates an austenitic iron base nickel-free alloy comprising in general between about 0.5% and about 1.0% carbon, from about 7.0% to 14.0% manganese, from about 12.0% to about 18.0% chromium, from about 1.5% to about 6.0% molybdenum, from about 0.5% to about 2.0% vanadium, from about 0.2% to about 0.5% nitrogen, from about 0.4% to about 3.5% of columbium and/or tantalum, from about 1.0% to about 4.0% copper and the balance iron with incidental impurities. Reference is directed to Table I which contains the chemical com-

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position of the alloy of this invention as illustrated both within the general range and the optimum range of composition.

Table I.—Chemical composition

[Percent by weight.]

Element	General Range	Optimum Range
C.....	0.5-1.0	0.65-0.75
Mn.....	7.0-14.0	8.0-10.0
Cr.....	12.0-18.0	14.0-16.0
Mo.....	1.5-6.0	2.5-3.5
V.....	0.5-2.0	0.5-1.0
N ₂	0.2-0.5	0.3-0.45
Co+Ta.....	0.4-3.5	0.6-1.2
Cu.....	1.0-4.0	2.5-3.2
Fe.....	Balance	Balance

It is to be noted in Table I that where the balance of the alloy is reported as containing iron, it will be appreciated that up to 1.5% of incidental impurities normally found in the making of such alloys may be present. Included within this category is the element silicon which in normal melting practices is usually present as a result of the deoxidation of such alloys. The normal silicon content in this alloy appears to be about 0.4%.

Each of the elements present within the alloy of this invention performs a specific function and is necessary within the range given hereinbefore in Table I. It is only through the proper proportioning of each of the elements to each other and within the range given which makes it possible to obtain the desired end result; namely, an alloy having superior strength at elevated temperatures of up to 1500° F. Carbon must be present within the alloy in the range between 0.50% and 1.0%. It performs the function of contributing to the superior strength of the alloy and its austenitic character without adversely affecting its corrosion and oxidation resistance. Carbon contents below about 0.50%, for example in the region of about 0.40%, result in the microstructure exhibiting islands of ferrite in an austenitic matrix. The presence of ferrite within the alloy produces an adverse effect upon the mechanical properties, especially reduced rupture strength. On the other hand, the carbon content must be limited to a maximum of about 1.0%. While greater carbon contents could be employed without adversely affecting the mechanical properties, it has been found that this is the upper limit where the alloy can be hot worked, for example, by forging. Within the general range of carbon, as set forth hereinbefore, it has been found that optimum results are obtained when about 0.65% carbon is present. This is especially true with respect to austenite stability. The combination of optimum austenite stability commensurate with hot workability and superior strength is present within the alloy of this invention when the carbon content does not exceed about 0.75%.

Manganese is the element which primarily contributes to the formation and stabilization of the austenite phase in this alloy. As set forth in Table I, at least 7.0% manganese is necessary in order to have a completely austenitic structure. While a manganese content in excess of 14% will not adversely affect the alloy from the standpoint of phase stabilization, it will be appreciated that the rupture strength is impaired to a considerable degree. Within the general range, as set forth hereinbefore, it has been found that optimum results are obtained when the manganese content is maintained within the range between about 8.0% and about 10.0%. Good austenite stabilization and hot workability commensurate with the most favorable combination of mechanical properties, especially strength, are obtained when the manganese is maintained within this range.

Chromium, a strong ferrite-forming element, is essential to the composition of this alloy because of its contribution to the corrosion and oxidation resistance of the alloy. In this respect, it has been found that at least 12.0% chromium is necessary. However, chromium contents in excess of 18.0% have an adverse effect on the rupture strength and ability to form austenite. When it is desired to provide the alloy with the optimum corrosion and oxidation resistance together with optimum mechanical properties and austenite stability, it is preferred to maintain the chromium content within the range between 14.0% and 16.0%.

Added resistance to corrosion as well as a great increase in strength is obtained with the use of molybdenum within the range between 1.5% and 6.0% in the alloy of this invention. Molybdenum contents of less than 1.5% do not provide any noticeable increase in strength, whereas molybdenum contents in excess of about 6.0% appear to make the alloy unworkable. Of particular interest is the fact that molybdenum as well as chromium enhances the corrosion resistance properties in this alloy, the former being especially effective where the corrosive media contains a halogen compound. For the optimum combination of strength and corrosion resistance along with austenite stability, it is preferred to maintain the molybdenum content within the range between 2.5% and 3.5%. When the molybdenum content is maintained within this range, no difficulty is encountered in fabricating this alloy. It must be noted also that while molybdenum is also added to the alloy for its effect upon the strengthening of the solid solution, it cannot be interchanged with tungsten because, while tungsten has a similar effect upon the mechanical properties, tungsten raises the density of the alloy and reduces its strength-to-weight ratio.

Vanadium within the range given hereinbefore in Table I appears to contribute to the strength of the alloy and at least 0.5% is necessary for any noticeable effect thereon. However, increasing the vanadium content in excess of 2.0% reduces the ductility of the alloy to a sufficient degree to make the alloy brittle and unworkable. The optimum strength and ductility are obtainable when the vanadium content is maintained within the range between 0.5% and 1.0%.

Nitrogen materially contributes to the austenitic sta-

sound ingots having an excess of gas cavities contained therein. Optimum results as respects austenite stability, rupture strength and sound ingot structure are obtained when the nitrogen content is within the range between 0.3% and 0.45%. Considerable improvement in the strength of this alloy is obtained from the use of the strong carbide-forming elements, columbium and tantalum. At least 0.4% of columbium or tantalum or the combination thereof is necessary for an appreciable strengthening of the alloy. However, since these elements are strong carbide-forming elements and materially contribute to the formation of ferrite, it is necessary that the upper limit of 3.5% is not exceeded because of the probability of forming ferrite within the alloy. Optimum strengthening appears to be obtained when the columbium and/or tantalum content is maintained within the range between 0.6% and 1.2%.

Of special importance is the use of copper in this alloy. Where at least 1.0% copper is present, an increase in ductility is noted. Also the strength of the alloy is greatly improved therewith. However, if the copper content is increased to amounts beyond 4.0%, the alloy is difficult to hot work. The optimum combination of strength and ductility commensurate with good forgeability is obtained where the copper content is within the range between 2.5% and 3.2%.

The balance of the alloy is substantially all iron with up to about 1.5% of incidental impurities. This includes residual amount of silicon which in normal melting processes is obtained primarily from the use of deoxidizing compounds and alloys, for example, calcium silicomanganese and other silicon-containing compounds. About 0.4% silicon is usually found along with residual amounts of incidental impurities which, in aggregate, do not exceed about 1.5% and which do not have a significant effect upon the chemical, physical or mechanical properties of the alloys of this invention.

In order to obtain a better understanding of the alloy and of the effect of each of the alloying elements thereon, reference is directed to Table II wherein the chemical composition of a number of alloys is listed, said alloys having been tested in the manner as set forth hereinafter. It is to be noted in Table II that compositions of these alloys fall both within and outside of the general range as was set forth hereinbefore in Table I.

Table II.—Chemical composition

[Percent by weight.]

Alloy	C	Mn	Si	Cr	Mo	V	N	Cb+Ta	Cu	Fe
H-205	0.60	6.25	0.50	14.90	3.30	0.56	0.34	0.49	-----	Bal.
H-107	0.63	8.36	0.48	14.96	3.00	0.62	0.31	0.52	-----	Bal.
H-206	0.65	12.68	0.56	14.76	3.28	0.54	0.44	0.53	-----	Bal.
H-457	0.70	8.71	0.18	14.98	3.06	0.45	0.09	0.62	3.15	Bal.
H-458	0.70	8.49	0.28	15.39	3.14	0.46	0.20	0.77	2.40	Bal.
H-459	0.68	8.36	0.22	15.32	2.88	0.66	0.30	0.89	2.94	Bal.
H-481	0.68	7.88	0.52	15.14	2.88	0.45	0.39	0.96	3.05	Bal.
H-106	0.65	8.22	0.48	12.20	3.00	0.62	0.29	0.52	-----	Bal.
H-108	0.73	8.53	0.48	18.12	3.08	0.65	0.35	0.63	-----	Bal.
H-109	0.71	8.58	0.42	21.30	3.20	0.59	0.35	0.55	-----	Bal.
H-392	0.55	8.62	0.40	15.52	3.18	0.12	0.37	1.07	-----	Bal.
H-393	0.67	8.73	0.38	15.72	3.14	0.56	0.38	1.12	-----	Bal.
H-394	0.72	8.80	0.35	15.60	3.06	0.98	0.33	1.12	-----	Bal.
K-159	0.43	8.38	0.46	15.69	3.34	0.55	0.29	0.07	3.29	Bal.
K-142	0.50	8.16	0.30	15.73	3.10	0.53	0.26	0.62	3.18	Bal.
K-154	0.67	8.10	0.35	15.48	3.04	0.43	0.41	1.10	3.40	Bal.
K-158	0.68	8.27	0.32	15.68	3.22	0.50	0.34	1.41	3.18	Bal.
H-312	0.77	8.87	0.66	15.18	3.12	0.57	0.38	0.95	-----	Bal.
H-377	0.68	8.67	0.19	15.30	3.22	0.56	0.33	0.79	0.62	Bal.
H-378	0.73	8.82	0.54	15.20	3.06	0.55	0.33	0.83	1.08	Bal.
H-379	0.73	8.69	0.38	15.38	3.12	0.47	0.36	0.90	2.10	Bal.
H-380	0.66	8.58	0.59	14.98	3.22	0.48	0.37	1.00	3.00	Bal.

bility of this alloy and its effect on the strength is outstanding. While a nitrogen content below about 0.2% is beneficial from the strength standpoint, it is preferred to maintain at least 0.2% nitrogen therein for proper austenite stability. On the other hand, nitrogen contents in excess of the upper limit of 0.5% result in un-

Each of the alloys set forth in Table II was subjected to the stress rupture test, both at 1200° F. and at 1500° F. A base composition comprising about 0.70% carbon, about 8.5% manganese, about 15.0% chromium, about 3.0% molybdenum, about 0.5% vanadium, about 0.35% nitrogen, about 0.90% columbium and/or tantalum,

about 3.0% copper and the balance substantially iron was selected and one element was varied in each series of tests. Thus, to illustrate the effect of chromium on the stress rupture properties of the alloy of this invention, a series of alloys having a base composition of about 0.70% carbon, about 8.5% manganese, about 3.0% molybdenum, about 0.5% vanadium, about 0.35% nitrogen, about 0.90% columbium and/or tantalum, about 3.0% copper with varying amounts of chromium, for example: 12.20%, 14.96%, 18.13%, 21.40% in alloys H-106, H-107, H-108, and H-109, respectively, and the balance iron were made and tested at the temperatures and stresses given hereinafter. The effect of each of the alloying elements on the base composition was thus determined.

Reference is directed to Table III and the test results recorded therein illustrating the effect of each of the alloying elements on the stress rupture properties of the alloy of this invention.

Table III.—Stress rupture properties

Alloy No.	1200° F.				1500° F.			
	Stress × 1000 (p.s.i.)	Life (Hrs.)	Elong. (percent)	Red of A. (percent)	Stress × 1000 (p.s.i.)	Life (Hrs.)	Elong. (percent)	Red of A. (percent)
H-205	60	43	1.8	2.5	15	476	8.5	8.5
H-107	60	129	4.1	4.0	15	1069	17.4	29.0
H-206	60	77	0.5	0.8	15	820	5.8	12.6
H-457	60	173	8.0	7.0	20	119	5.1	13.2
H-458	60	632	4.0	6.5	20	137	6.2	6.7
H-459	60	982	6.6	7.6	20	239	5.4	6.7
H-481	60	871	6.4	8.5	20	420	5.5	9.3
H-106	60	64	1.5	2.5	15	1578	4.8	4.0
H-108	60	186	2.8	2.0	15	668	5.1	27.6
H-109	60	189	0.9	1.0	15	226	7.4	12.0
H-392	60	50	2.9	6.0	20	70	55.6	77.0
H-393	60	71	0.3	0.3	20	218	17.3	30.9
H-394	60	137	0.9	0.0	20	238	4.1	3.2
K-139	60	6	4.0	7.0	20	79	5.6	9.3
K-142	60	34	2.4	6.5	20	296	14.0	21.0
K-154	60	26	1.0	1.6	20	265	5.7	7.4
K-158	60	30	0.6	2.0	20	143	5.1	6.3
H-312	60	130	1.8	3.5	20	87	30.4	66.4
H-377	60	157	3.8	4.1	20	90	40.3	72.2
H-378	60	396	9.2	11.8	20	70	32.4	64.4
H-379	60	381	10.3	20.7	20	138	16.7	20.7
H-380	60	472	11.0	19.1	20	168	19.2	37.8

¹ Test Discontinued.

By inspection of the test results recorded in Table III for alloys H-205, H-107 and H-206 which have a base composition within the limits 0.60% and 0.68% carbon, 14.76% to 14.96% chromium, 3.0% and 3.3% molybdenum, 0.54% and 0.62% vanadium, 0.31% and 0.44% nitrogen, 0.49% and 0.53% columbium and/or tantalum and the balance iron, it is seen that increasing the manganese from 6.25% and to 8.36% is effective for increasing the rupture life of these alloys when tested both at 1200° F. and 1500° F. under stresses of 60,000 p.s.i. and 15,000 p.s.i., respectively. Further increase in the manganese content of from 8.36% to 12.58% as in alloys H-107 and H-206 respectively decreased the strength as clearly set forth. Accordingly, it has been found that the optimum strength and ductility commensurate with excellent austenite stability are obtained when the manganese content is maintained within the range between 8.0% and 10.0% as set forth hereinbefore in Table I.

The effect of nitrogen on the stress rupture properties of these alloys is illustrated by reference to alloy Nos. H-457, H-458, H-459 and H-481 which have a nitrogen content varying between 0.09% and 0.39% and a base composition within the limits between 0.68% and 0.70% carbon, 7.88% and 8.71% manganese, 14.98% and 15.39% chromium, 2.88% and 3.14% molybdenum, 0.45% and 0.66% vanadium, 2.40% and 3.15% copper and the balance iron. Thus, when tested both at 1200° F. and 1500° F. and at stresses of 60,000 p.s.i. and 20,000 p.s.i., respectively, it is seen that a great increase in strength is noted when the nitrogen content is increased from 0.09% to 0.39%. This great increase in rupture

life is accomplished without an adverse effect upon the ductility of the alloy. When the nitrogen content is increased beyond the upper limit of 0.50%, the ingot which was made from an alloy containing such a high nitrogen content contained a significant amount of gas cavities to the extent that it was unusable. The greatest strength with excellent ductility is obtained when the nitrogen content is maintained within the range between 0.3% and 0.45%. Since nitrogen is an austenite-forming element, it is highly beneficial from the phase stabilization standpoint when maintained within the range between 0.2% and 0.5% as set forth in Table I.

Chromium a strong ferrite-forming element and the most important element in this alloy from the standpoint of corrosion and oxidation resistance, exerts a definite influence on the alloy of this invention. By inspection of Table III and the test results recorded therein for alloy Nos. H-106, H-107, H-108 and H-109 which have a chromium content varying from 12.20% to

21.77% in a base composition within the limits between 0.65% and 0.73% carbon, 8.22% and 8.58% manganese, 3.00% and 3.20% molybdenum, and 0.59% and 0.65% vanadium, 0.29% and 0.35% nitrogen, 0.52% and 0.63% columbium and/or tantalum and the balance iron, it is seen that, in general, increasing the chromium content results in a loss in the rupture life of the alloy. While the trend of decreasing rupture life with increasing chromium contents is not apparent when the alloys were tested at 1200° F. and under a stress of 60,000 p.s.i., the trend is unmistakably clear when the alloys were tested at 1500° F. and under a stress of 15,000 p.s.i. Note also that increasing the chromium content has the adverse effect of decreasing the ductility as measured by the percent elongation and reduction of area. Since the alloy of this invention is intended for use at temperatures of up to 1500° F. and higher, a chromium content within the range between 12.0% and 18.0% is necessary from the standpoint of resistance to oxidation and corrosion. However, while the lower chromium contents within the general range, that is, between 12.0% and 14.0%, appear to give the greatest rupture life, the optimum combination between rupture life, austenite stability, and corrosion and oxidation resistance is obtained where the chromium content is maintained within the range between 14.0% and 16.0%.

In the manufacture of master alloys for use in the steel industry, economy is of primary importance. Since technological difficulties make it impossible to economically supply a master alloy containing columbium which is devoid of tantalum, the alloy of this invention contains

columbium and/or tantalum. In any event, the effect of either is so substantially similar that substitution of one for the other or the combination of the two may be used without a noticeable variance in the mechanical properties of the alloy of this invention.

Reference is directed to alloys K-139, K-142, K-154 and K-158 of Table III which illustrate the effect on the rupture life of increasing the columbium and/or tantalum from 0.07% to 1.41% in an alloy having a base composition between 0.43% and 0.68% carbon, 8.10% and 8.38% manganese, 15.48% and 15.73% chromium, 3.04% and 3.34% molybdenum, 0.43% and 0.53% vanadium, 0.26% and 0.41% nitrogen, 3.18% and 3.40% copper and the balance iron. As shown therein, the rupture life was improved, both at 1200° F. and at 1500° F., when the alloys were tested at stresses of 60,000 p.s.i. and 20,000 p.s.i., respectively. Below about 0.4% columbium and/or tantalum, little increase in the rupture life is noted. However, if the columbium and/or tantalum content is increased beyond about 3.5%, the ductility of the alloy is seriously affected. Optimum rupture life commensurate with adequate ductility is obtained when the columbium and/or tantalum content is within the range between 0.6% and 1.2%.

Of particular significance is the effect of copper on the the rupture life of the alloy of this invention. Alloy Nos. H-312, H-377, H-378, H-379, and H-380 illustrate the effect of increasing the copper content from 0% up to 3.0% on the rupture life and rupture ductility in a base composition containing between 0.66% and 0.77% carbon, 8.58% and 8.87% manganese, 14.98% and 15.38% chromium, 3.06% and 3.22% molybdenum, 0.47% and 0.57% vanadium, 0.33% and 0.38% nitrogen, 0.79% and 1.0% columbium and/or tantalum and the balance iron with incidental impurities. As clearly shown by the test results recorded in Table III, increasing the copper content is effective for increasing the rupture life and rupture ductility when the alloys are tested both at 1200° F. and 1500° F. and under stresses of 60,000 p.s.i. and 20,000 p.s.i., respectively.

In practicing this invention, it has been found that both carbon and molybdenum exert a definite influence on the alloy of this invention. Carbon must be present in an amount of not less than 0.50% in order to insure a completely austenitic structure and adequate strength. However, if the carbon content exceeds 1.0%, the alloy becomes difficult to fabricate, the corrosion and oxidation resistance is impaired and more important, the ductility is adversely affected. Optimum results occur where the carbon content is maintained within the range between 0.65% and 0.75%. The primary influence of carbon is noted in its effect upon the strength of the alloy within the range between 0.65% and 0.75%. On the other hand, molybdenum, a strong ferrite-forming element while materially contributing to the strength of the alloy, is effective for increasing the corrosion resistance of the alloy especially in an environment containing a halogen compound. Molybdenum strengthens the alloy by being taken into solution thereby hardening the matrix of the alloy. At least 1.5% is necessary for an appreciable strengthening to take place. If the molybdenum content is increased to amounts of greater than 6%, the alloy becomes unforgeable, and, in addition, the alloy will possess a microstructure evidencing small islands of ferrite within the austenite matrix. The optimum balance between the mechanical, physical, and chemical properties appears to occur where the molybdenum content is maintained within the range between 2.5% and 3.5% as set forth hereinbefore in Table I. It is believed that vanadium also contributes to the strength of this alloy, and it should be present within the limits set forth in Table I.

While the proper balance between each of the alloying elements is necessary in order to obtain the optimum properties within the alloy of this invention, it is also necessary to provide the alloy with the proper heat treat-

ment in order to develop these properties. Also, within the framework of the analysis as set forth in Table I, it is possible to alter the heat treatment so as to accentuate one property to its ultimate capacity within a given analysis at the expense of the other properties. A number of tests conducted on alloy H-380 indicated that the following heat treatment is preferred.

The alloy in the semi-finished condition, that is, in the form of sheet, strip, rod, bar, wire, and the like is preferably heat treated by a solution heat treatment at a temperature in the range between 2050° F. and 2250° F. for a time period ranging between ½ hour and 8 hours, depending upon the thickness. In any event, the alloy should be maintained at a minimum of 2050° F. for at least ½ hour. Holding the alloy at temperature for more than 8 hours does not appear to contribute to the ultimate mechanical properties and is costly and time consuming. Increasing the temperature about 200° F. is effective for increasing the rupture strength but at the expense of the ductility. The purpose of the solution heat treatment is to take the alloying elements into solution within the austenite so that their effects can be realized either in the strengthening of the matrix or in the formation of a hardening precipitate. Following the solution heat treatment, it is preferred to quench the solution heat treated alloy at a rate sufficiently fast to prevent any reprecipitation of any of the elements or compounds taken into the austenite during the solution heat treatment. This is most conveniently accomplished by quenching into water. However, it will be appreciated that where the alloy is sufficiently thin, oil or even air quenching may be used. Of course, if distortion is a serious problem, oil quenching may be preferred. The alloy when thus quenched is in a soft condition making it amenable for forming or machining to the desired finished component.

In order to develop the optimum combination of mechanical properties, the alloy in the finished form of component, resulting from forming and/or machining, is age hardened by heating to a temperature within the range between 1250° F. and 1550° F. for a time period of between 1 and 48 hours. Following the age hardening treatment, the alloy is air cooled. It is after this aging heat treatment that the alloy possesses the optimum combination of properties.

In producing the alloy of this invention, substantially any of the well known steel-making methods may be used; for example, carbon electrode electric arc, consumable electrode electric arc and induction furnace melting procedures. Standard steel mill equipment, for example, forges, presses, rolling mills, and extrusion presses are utilized in working the material into the semi-finished mill product. In all, these are no special skills, equipment or techniques used in the production of this alloy and the raw materials are readily available. The alloy possesses outstanding properties and can be used at temperatures of up to 1500° F.

We claim:

1. An austenitic precipitation hardening nickel-free alloy consisting of, from 0.5% to 1.0% carbon, from 7.0% to 14.0% manganese, from 12.0% to 18.0% chromium, from 1.5% to 6.0% molybdenum, from 0.5% to 2.0% vanadium, from 0.4% to 3.5% of the sum of columbium plus tantalum, from 0.2% to 0.5% nitrogen, from 1.0% to 4.0% copper, and the balance iron with incidental impurities.

2. An austenitic precipitation hardening nickel-free alloy consisting of, from 0.65% to 0.75% carbon, from 8.0% to 10.0% manganese, from 14.0% to 16.0% chromium, from 2.5% to 3.5% molybdenum, from 0.5% to 1.0% vanadium, from 0.6 to 1.2% of the sum of columbium plus tantalum, from 0.3% to 0.45% nitrogen, from 2.5% to 3.2% copper, and the balance iron with incidental impurities.

3. An austenitic precipitation hardening nickel-free

alloy consisting of, about 0.66% carbon, about 8.5% manganese, about 14.9% chromium, about 3.2% molybdenum, about 0.5% vanadium, about 1.0% of the sum of columbium plus tantalum, about 0.37% nitrogen, about 3.0% copper, and the balance iron with incidental impurities.

4. An article of manufacture for use in highly stressed moving parts operating at temperatures of up to 1500° F. formed from an austenitic precipitation hardening nickel-free alloy consisting of, 0.5% to 1.0% carbon, 7.0% to 14.0% manganese, 12.0% to 18.0% chromium, 1.5% to 6.0% molybdenum, 0.5% to 2.0% vanadium, 0.9% to 3.5% of the sum of columbium plus tantalum, 0.2% to 0.5% nitrogen, 1.0% to 4.0% copper, and the balance iron with incidental impurities.

5. An article of manufacture for use in highly stressed moving parts operating at temperatures of up to 1500° F. formed from an austenitic precipitation hardening nickel-free alloy consisting of, 0.65% to 0.75% carbon, 8.0% to 10.0% manganese, 14.0% to 16.0% chromium, 2.5% to 3.5% molybdenum, 0.5% to 1.0% vanadium, 0.6% to 1.2% of the sum of columbium plus tantalum,

0.3% to 0.45% nitrogen, 2.5% to 3.2% copper and the balance iron with incidental impurities.

6. A precipitation hardened article of manufacture suitable for use under high stress at temperatures of up to 1500° F. consisting of 0.5% to 1.0% carbon, 7.0% to 14.0% manganese, 12.0% to 18.0% chromium, 1.5% to 6.0% molybdenum, 0.5% to 2.0% vanadium, 0.2% to 0.5% nitrogen, 0.4% to 3.5% of at least one metal selected from the group of columbium and tantalum, 1.0% to 4.0% copper, and the balance iron with incidental impurities, and characterized by having a rupture life of substantially not less than 70 hours at a temperature of 1500° F., and at a stress of 20,000 p.s.i.

7. An austenitic precipitation hardening nickel-free alloy consisting of, from 0.5% to 1.0% carbon, from 7.0% to 14.0% manganese, from 12.0% to 18.0% chromium, from 1.5% to 6.0% molybdenum, from 0.5% to 2.0% vanadium, from 0.4% to 3.5% of at least one metal selected from the group of columbium and tantalum, from 0.2% to 0.5% nitrogen, from 1.0% to 4.0% copper, and the balance iron with incidental impurities.

No references cited.