

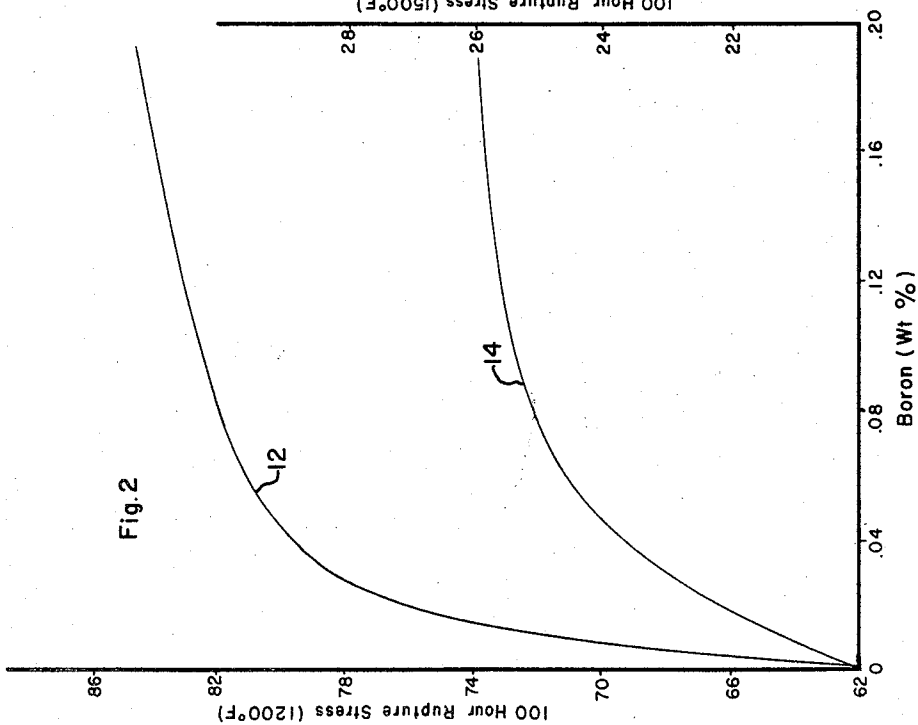
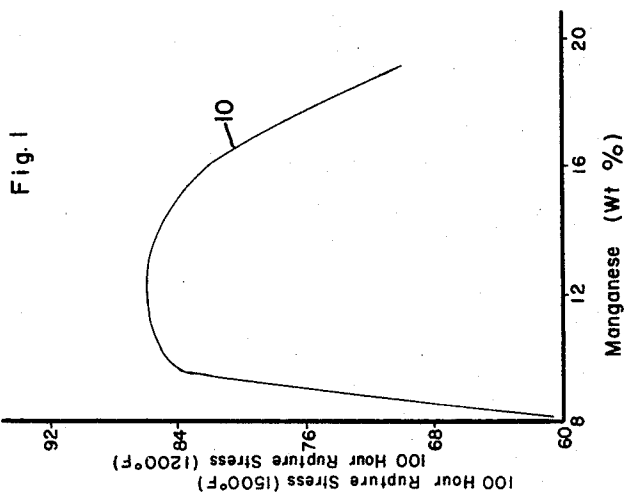
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NICKEL-FREE AUSTENITIC ELEVATED TEMPERATURE ALLOY

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1

2,948,604

NICKEL-FREE AUSTENITIC ELEVATED
TEMPERATURE ALLOY

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4 Claims. (Cl. 75-126)

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

Heretofore, many alloys have been made and used as turbine parts and the like where it is necessary that the alloys possess sufficient hardness, strength and corrosion resistance to withstand the stresses and corrosive conditions encountered under the operating conditions at elevated temperatures of up to about 1500° F. and higher. Some available prior art alloys have been made and used which possess suitable mechanical properties for use at these elevated temperatures, but these same alloys are not adequate from the standpoint of either their chemical properties, for example, corrosion resistance, or their physical properties, for example, dimensional stability. Other alloys have been made which compromise between chemical, physical and mechanical properties, but usually such alloys contain high amounts of nickel or other strategic alloying elements. These are the so-called super alloys, and they are characterized by being quite expensive from the standpoint of material and fabrication costs. The alloy of this invention is characterized by having an optimum combination of chemical, physical and mechanical properties, freedom from costly and strategic alloying elements, and economical from the standpoint of material and fabrication costs.

An object of this invention is to provide an austenitic iron base nickel-free alloy which is capable of withstanding high stresses at temperatures of up to 1500° F. and higher.

Another object of this invention is to provide an austenitic iron base nickel-free alloy having optimum amounts of manganese and chromium with small amounts of carbon, silicon, molybdenum, vanadium, nitrogen and boron as essential alloying elements and which is suitable for use at high stresses at temperatures of up to about 1500° F. and higher.

A more specific object of this invention is to produce an iron base nickel-free alloy containing critical amounts of carbon, silicon, manganese, chromium, molybdenum, vanadium, nitrogen and boron as essential alloying elements and which is suitable for use at high stresses at a temperature of up to 1500° F. and higher.

These and other objects of this invention will become apparent when taken in conjunction with the following description and the drawings in which:

Figure 1 is a graph, the curve of which illustrates the effect of manganese on the rupture properties of the alloy, and

Fig. 2 is a graph, the curves of which illustrate the effect of boron on the rupture properties of the alloy.

In its broader aspects, the alloy of this invention comprises between about 0.20% and about 0.35% carbon, between about 10.0% and about 15.0% manganese, up to about 0.75% silicon, between about 11.5% and about 13.5% chromium, between about 2.0% and about 3.5% molybdenum, between about 0.7% and 1.2% vanadium, between about 0.1% and about 0.3% nitrogen, between about 0.01% and about 0.3% boron and the balance substantially iron with incidental impurities not exceeding

2

about 2.0% which are usually found in the manufacture of steel such as copper, cobalt, nickel, phosphorus, sulfur and the like, and which do not detrimentally affect the alloy. Reference is directed to Table I which sets forth the general range and the optimum range of the composition of the alloy of this invention. It is to be noted that where the balance is reported as iron, such balance includes the incidental impurities as set forth hereinbefore.

TABLE I

Composition (percent by weight)

Element	General Range	Optimum Range
C.....	0.20-0.35	0.22-0.32
Mn.....	10.00-15.00	11.0-14.0
Si.....	0.0-0.75	0.0-0.4
Cr.....	11.50-13.50	12.0-13.0
Mo.....	2.0-3.5	2.5-3.25
V.....	0.7-1.2	0.8-1.1
N.....	0.1-0.3	0.15-0.25
B.....	0.01-0.3	0.02-0.20
Fe.....	Balance	Balance

Each of the elements performs a specific function within the alloy of this invention. For example, carbon imparts the requisite strength to the alloy and at least 0.20% carbon is also needed to maintain a stable austenitic structure within the alloy. Preferably the carbon content will not exceed a maximum of about 0.35%, because it has been found that higher carbon contents lower the ductility of the alloy of this invention. Carbon also contributes to the strength and hardness of the alloy. While carbon is a strong austenitizing element, the predominant austenitizing element of this alloy is manganese, it being found that at least 10.0% is needed to insure a completely austenitic structure. Manganese contents in excess of about 15.0% do not contribute to the stability of the austenite and may detract from the attainable mechanical properties. The optimum combination between austenitic stability commensurate with good mechanical properties is obtained when the manganese content is maintained within the range between about 11.0% and about 14.0%.

Not less than 11.5% chromium is needed in order to impart sufficient corrosion resistance to the alloy, especially when it is used in an atmosphere containing combustion products of leaded fuels, such as the types which are used in gas turbines or other engines. The chromium content should not exceed about 13.5%. Chromium contents in excess of about 13.5% have a detrimental effect on the mechanical and physical properties of the alloy of this invention because these higher chromium contents greatly affect the formation of both alpha and delta ferrite.

Molybdenum and vanadium within the ranges given hereinbefore in Table I function to impart additional strength to the alloy of this invention by strengthening the solid solution of the matrix. In addition, vanadium also contributes to the precipitation hardening phenomenon of the alloy and thereby materially contributes to the strength. Nitrogen within the range given has a strengthening effect upon the alloy of this invention and materially contributes to the austenitic stability of the alloy. Silicon, while used predominantly as a deoxidizer, may contribute somewhat to the oxidation resistance of the alloy when the silicon is taken within solution. Boron is used in the alloy in order to increase the rupture life and to provide the alloy with sufficient ductility to be relatively free from notch-rupture sensitivity. The balance of the alloy is predominantly all iron with not more than 2% of incidental impurities as set forth hereinbefore.

The alloy of this invention is an age hardenable alloy.

In order to obtain the optimum mechanical properties, the alloy is preferably solution heat treated at a temperature in the range between about 2000° F. and about 2100° F. for a time period ranging between about 10 minutes and 6 hours. Thereafter, the solution heat treated alloy is rapidly quenched, usually in water, although in some instances either oil or air will suffice. As quenched the alloy is usually soft and machinable. Following the quench, the alloy is aged at a temperature in the range between about 1250° F. and about 1400° F. for a time period ranging between about 8 and 30 hours. Thereafter, the alloy is air cooled.

Reference is directed to Table II which contains the chemical analysis of a series of alloys which were made and tested to illustrate the effect of some of the alloying elements on the rupture life of the alloy. It is to be noted that the alloys set forth in Table II are both within and outside the general range as set forth hereinbefore in Table I.

TABLE II

Chemical analysis.—Percent by weight

Heat No.	C	Mn	Si	Cr	V	Mo	N	B	Fe
H-419	.29	18.34	.28	12.50	.84	3.06	.19	.20	Bal.
H-535	.31	5.83	.24	12.94	.88	3.14	.14	.19	Bal.
H-536	.28	12.20	.18	12.86	1.05	3.14	.14	.20	Bal.
H-668	.29	17.91	.12	12.97	.78	3.22	.17	.19	Bal.
H-701	.30	7.81	.14	12.98	.67	3.10	.13	.15	Bal.
H-702	.30	9.57	.24	12.82	.76	2.98	.15	.16	Bal.
H-703	.29	13.85	.20	12.74	.77	2.92	.15	.17	Bal.
H-704	.30	16.24	.18	12.69	.75	2.88	.16	.20	Bal.
H-822	.26	11.12	.18	12.89	.76	3.24	.21	.20	Bal.
H-932	.26	12.63	.16	12.77	1.04	3.34	.26	.011	Bal.
H-933	.23	12.36	.12	12.81	1.04	3.24	.20	.049	Bal.
H-934	.23	12.32	.11	12.66	1.05	3.22	.23	.081	Bal.
H-935	.23	12.10	.13	12.70	1.05	2.92	.24	.099	Bal.
H-936	.28	12.36	.16	12.77	1.01	3.24	.21	.193	Bal.
H-941	.24	11.83	.10	12.89	1.05	3.04	.16	—	Bal.
9X-461	.30	19.71	.09	12.60	1.01	2.88	.23	.12	Bal.
9X-466	.31	19.10	.11	12.63	1.16	3.14	.21	.26	Bal.
K-172	.18	13.07	.11	12.65	1.00	3.39	.22	.004	Bal.
K-173	.22	12.63	.11	12.50	.98	3.33	.23	.010	Bal.
K-174	.24	12.01	.08	12.46	1.02	3.52	.22	.026	Bal.
K-197	.24	12.89	.02	12.08	1.09	2.88	.21	.042	Bal.
K-198	.25	12.80	.04	12.58	1.09	2.86	.22	.040	Bal.

Reference is directed to Table III which illustrates the effect of manganese upon the stress rupture properties of a portion of the alloys set forth hereinbefore in Table II. It is to be noted that these alloys have been subjected to heat treatment consisting of a solution heat treatment at a temperature of 2050° F. for one hour followed by a rapid quench in water and thereafter an aging treatment at the temperature of 1300° F. for a time period of 16 hours followed by air cooling. The test bars of the alloys were stressed at their respective levels and temperatures indicated, and the time required to produce rupture was measured.

TABLE III

Stress rupture properties

[Heat treatment: 2050° F.—1 hr.—W.Q.—1300° F.—16 hrs.—A.C.]

Heat No.	Mn Per-cent	1200° F.—65,000 p.s.i.			1500° F.—20,000 p.s.i.			Stress for Rupture in 100 Hrs. at 1000 p.s.i.)	
		Hrs.	El. (Per-cent)	R.A. (Per-cent)	Hrs.	El. (Per-cent)	R.A. (Per-cent)	1200° F.	1500° F.
H-535	5.83	(1)	26	40	307	27	59	—	—
H-701	7.81	57	13	15	269	41	73	60	22.5
H-702	9.57	521	13	46	504	—	71	83	23
H-822	11.12	795	19	56	366	34	70	88	21.5
H-536	12.20	557	14	30	268	20	68	80	22
H-703	13.85	736	15	45	263	22	70	86	23.5
H-704	16.24	565	13	43	253	42	73	80	22.5
H-419	18.34	376	15	53	218	34	76	78	23
H-668	17.91	340	14	56	188	15	45	75	22
9X-461	19.71	167	16	40	142	24	68	68	21
9X-466	19.10	255	3	4	139	26	68	69	21

(1) Broke on loading.

Referring specifically to the test results recorded hereinbefore in Table III, it is seen that increasing the manganese content from 5.83% up to 9.57% in alloys having a nominal composition within the range between 0.26% and 0.31% carbon, 0.09% and 0.28% silicon, 12.5% to 12.98% chromium, 0.67% and 1.16% vanadium, 2.88% and 3.24% molybdenum, 0.13% and 0.23% nitrogen, 0.12% boron and the balance iron with incidental impurities is effective for producing a substantial increase in the rupture life of these alloys when tested both at 1200° F. and at 1500° F. and under stresses of 65,000 p.s.i. and 20,000 p.s.i. respectively. It will be appreciated that these manganese contents are outside of the range, as set forth hereinbefore in Table I; however, when the manganese content is maintained within the range between 11.12% and 13.85%, it is seen that there is an outstanding rupture life exhibited by the alloys as illustrated by alloys H-822, H-536 and H-703. Increasing the manganese content beyond about 15.0%, as for example in alloys H-704, H-419, H-668, 9X461 and 9X469, is effective for producing a substantial decrease in the rupture life of these alloys. This same trend is apparent both at 1200° F. and at 1500° F. with the alloys under the respective stresses as set forth hereinbefore. Ductilities of these alloys are excellent when compared with similar alloys commercially available. The effect of manganese is more clearly illustrated by reference to Fig. 1 which graphically illustrates the effect of the manganese content on the stress required to produce rupture in 100 hours at 1200° F. Curve 10 of Fig. 1 clearly illustrates that the optimum stress rupture properties are obtained where the manganese content is maintained within the range between about 10.0% and about 15.0%. It is, therefore, apparent that the manganese content must be maintained within the range between 10.0% and 15.0% and preferably within the range between 11.0% and about 14.0%.

Reference is directed to Table IV which illustrates the effect of boron on the stress rupture properties of the alloy of this invention. The alloys, as set forth hereinbefore in Table IV, were first subjected to a solution heat treatment at 2050° F. for a time period of 1 hour followed by a rapid quench in water and thereafter aged at a temperature of 1325° F. for a time period of about 32 hours and thereafter air cooled. The stress rupture tests were made both at 1200° F. and 1500° F. and at stresses of 65,000 p.s.i. and 20,000 p.s.i., respectively.

TABLE IV

Stress rupture properties

[Heat treatment: 2050° F.—1 hr.—W.Q.—1325° F.—32 hrs.—A.C.]

Heat No.	Mn Per-cent	B Per-cent	1200° F.—65,000 p.s.i.			1500° F.—20,000 p.s.i.		
			Hrs.	El. (Per-cent)	R.A. (Per-cent)	Hrs.	El. (Per-cent)	R.A. (Per-cent)
H-941	11.88	—	43	12	33	88	26	50
K-172	13.07	.004	51	15	48	96	35	59
K-173	12.63	.010	356	17	53	156	25	66
H-932	12.63	.011	300	14	41	169	15	48
K-174	12.01	.026	651	11	37	264	27	70
K-197	12.89	.042	851	15	48	—	—	—
H-933	12.36	.049	737	10	31	419	31	69
H-934	12.32	.081	592	15	39	305	28	75
H-935	12.10	.14	789	14	45	565	29	73
H-936	12.36	.193	762	14	45	639	14	55

Referring more particularly to the test results recorded in Table IV and especially heats H-941, K-172 and K-173, it is immediately seen that by increasing the boron content from traces up to 0.010% is effective for producing an outstanding increase in the rupture life of these alloys. This same increase in the rupture life is noted both in the alloys when tested at 1200° F. and at 1500° F. Excellent results are obtained when the boron contents of the alloys are maintained within the range

between 0.010% and about 0.40% and preferably within the range between 0.02% and 0.20% as illustrated by heats H-932, K-174, K-197, H-933, H-934, H-935 and H-936. Substantially similar results are illustrated at both 1200° F. and at 1500° F. Reference is directed to Fig. 2 which graphically illustrates the effect of boron on the 100-hour rupture strength at 1200° F. and at 1500° F. for the alloys set forth hereinbefore in Table IV. Curve 12 of Fig. 2 illustrates the effect of increasing the boron content on the 100-hour rupture stress at 1200° F. and curve 14 illustrates the effect of boron on the 100-hour rupture stress at 1500° F. It is immediately seen from curves 12 and 14 of Fig. 2 that at least 0.01% boron is necessary in order to show any significant increase in the 100-hour rupture stress. Optimum results appear to be obtained when the boron content is maintained within the range between 0.02% and about 0.20%. From the foregoing, it is apparent that it is necessary to maintain a critical balance between the alloying elements in order to obtain outstanding properties capable of being produced within the alloy of this invention.

This alloy is effective for use in engine parts of gas turbines and other high temperature applications where an outstanding combination of strength, corrosion resistance and ductility is required at elevated temperatures of up to 1500° F. and higher. No particular skills nor equipment are necessary in practicing this invention since the alloy can be produced by ordinary air melting techniques which are commercially employed in the metal industry.

We claim:

1. An austenitic iron base nickel-free alloy suitable for use at temperatures of up to 1500° F. and having a composition including from about 0.20% to about 0.35% carbon, from about 10.0% to about 15.0% manganese, to about 0.75% silicon, from about 11.5% to about 13.5% chromium, from about 2.0% to about 3.5% molybdenum, from about 0.7% to about 1.2% vanadium, from about 0.10% to about 0.30% nitrogen, from about 0.01% to

about 0.40% boron and the balance substantially iron with incidental impurities.

2. An austenitic iron base nickel-free alloy suitable for use at temperatures of up to 1500° F. and having a composition including from about 0.22% to about 0.32% carbon, from about 11.0% to about 14.0% manganese, to about 0.40% silicon, from about 12.0% to about 13.0% chromium, from about 2.5% to about 3.25% molybdenum, from about 0.8% to about 1.1% vanadium, from about 0.15% to about 0.25% nitrogen, from about 0.02% to about 0.20% boron and the balance substantially iron with incidental impurities.

3. An austenitic iron base nickel-free alloy suitable for use at temperatures of up to about 1500° F. and having a composition including about 0.23% carbon, about 12.3% manganese, about 0.12% silicon, about 12.8% chromium, about 1.0% vanadium, about 3.2% molybdenum, about 0.2% nitrogen, about 0.05% boron and the balance substantially iron with incidental impurities.

4. An age hardened article of manufacture suitable for use under high stresses and at elevated temperatures of up to 1500° F., comprising an alloy having a composition within the range between about 0.20% and about 0.35% carbon, between about 10.0% and about 15.0% manganese, about 0.75% silicon, between about 11.5% and about 13.5% chromium, between about 2.0% and about 3.5% molybdenum, between about 0.9% and about 1.2% vanadium, between about 0.10% and about 0.30% nitrogen, between about 0.01% and about 0.40% boron and the balance substantially iron with incidental impurities, the alloy being characterized by having a 100-hour rupture stress of at least 20,000 p.s.i. at 1500° F.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,948,604

August 9, 1960

Richard Reed MacFarlane et al.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 5, line 35, and column 6, line 7, after "manganese," each occurrence, insert -- up --; column 6, line 25, after "manganese," insert -- up to --.

Signed and sealed this 4th day of April 1961.

(SEAL)

Attest: ERNEST W. SWIDER

XXXXXXXXXXXX

Attesting Officer

ARTHUR W. CROCKER
Acting Commissioner of Patents