

Jan. 30, 1968

A. E. NEHRENBURG ET AL

3,366,473

HIGH TEMPERATURE ALLOY

Filed Nov. 17, 1965

3 Sheets-Sheet 1

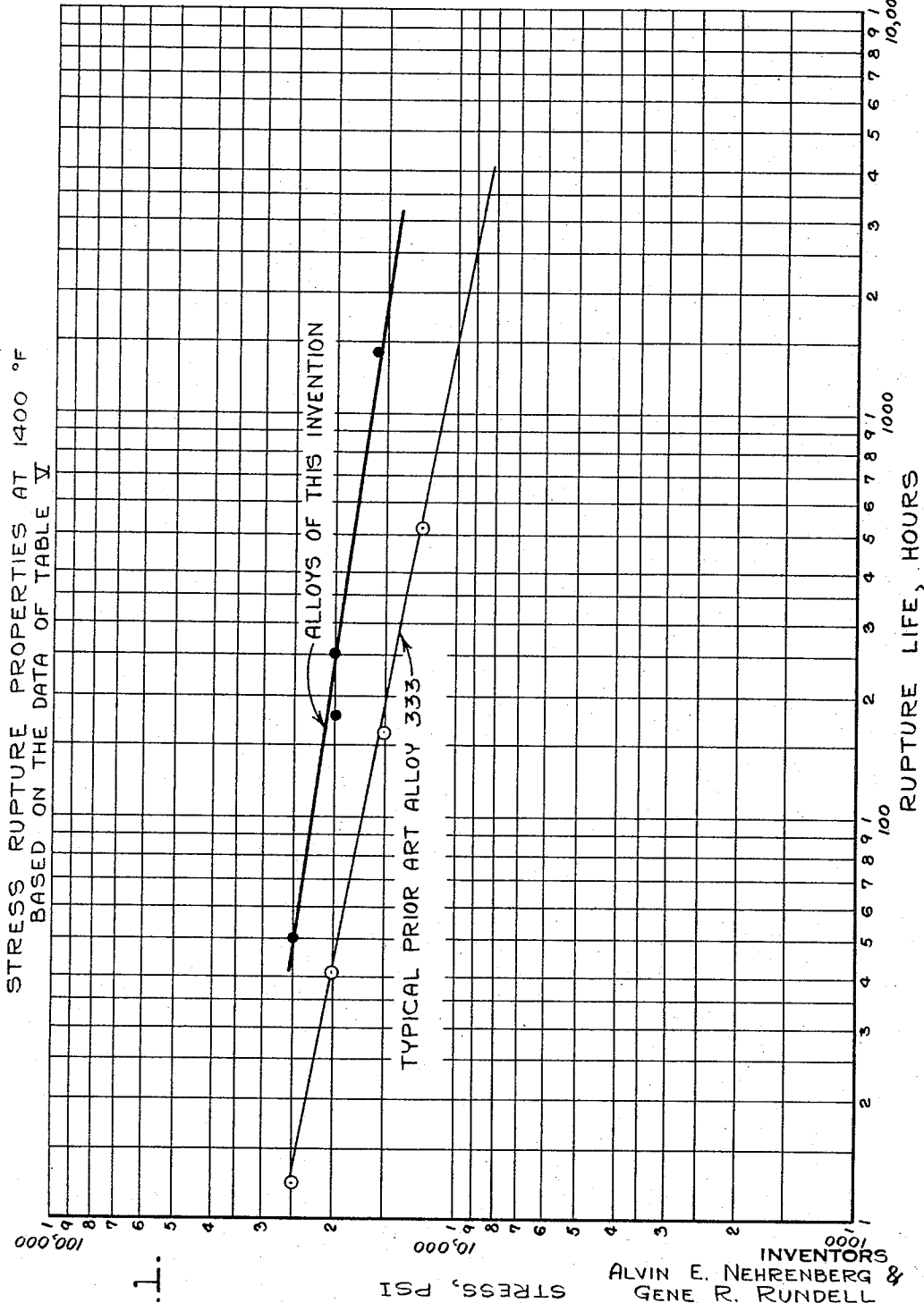


Fig. 1.

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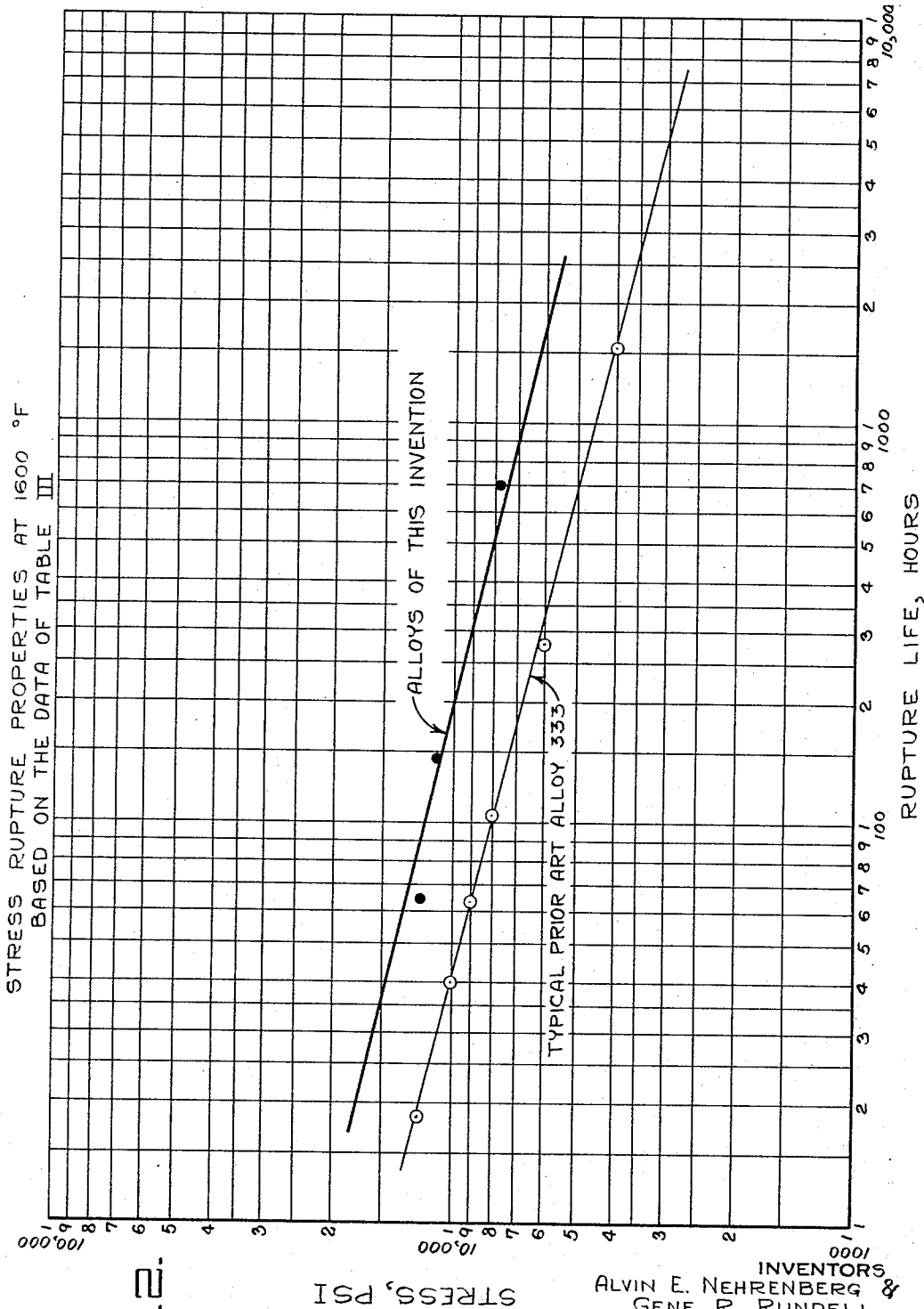
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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

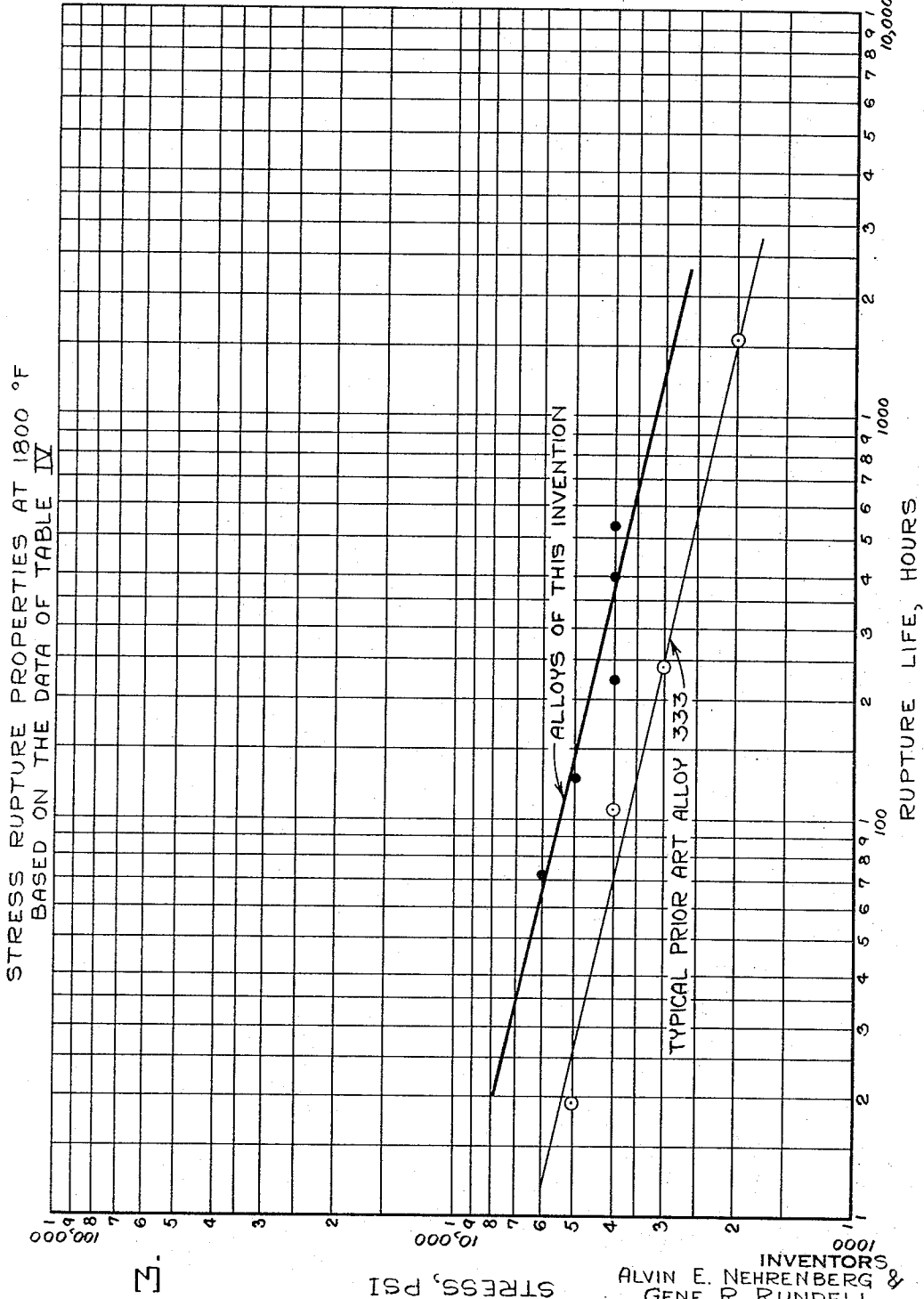


Fig. 2

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3,366,473

HIGH TEMPERATURE ALLOY

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5 Claims. (Cl. 75-128)

This invention relates to high temperature or heat resisting alloys, and more particularly, to heat resisting alloys containing nickel, chromium, molybdenum tungsten and cobalt as major alloying elements.

Heat resisting alloys are characterized as having high strength at elevated temperatures in combination with resistance to chemical deterioration on extended exposure to a variety of industrial environments which might be oxidizing, reducing, carburizing, nitriding, or sulfurizing. These alloys are useful materials for the fabrication of equipment and accessories used in the heat treatment of metals and alloys, in chemical processing operations, or for components for jet engines or stationary turbines where strength and oxidation resistance or high temperature corrosion resistance is required.

There is a continuing demand for material improvement or innovations which will result in longer life for a particular part or accessory, or equivalent life at lower initial cost. The realization of such goals is contingent, at least in part, upon the development of improved material characteristics such as greater strength or greater resistance to some particular corrosive environment.

The advantages and characteristics of the alloys of the present invention will be clarified in the ensuing discussion. U.S. Patent 2,955,934 of common ownership with the present application, discloses an improved high temperature alloy which has gained commercial acceptance because of its high strength at elevated temperatures in combination with good high temperature corrosion resistance. The nominal composition of the alloy is as follows: Ni 46%, Cr 25%, Mo 3%, W 3% and Co 3%.

The alloy of the present invention constitutes an improvement on that of said patent in the inclusion of boron in a critical amount and preferably also nitrogen in a critically limited amount, for imparting at least 50% greater strength than the alloy of said patent and without sacrificing any of the other desirable properties thereof including elevated temperature corrosion resistance. This represents a contribution to the heat resisting industry in that a saving of 50% in material costs can be realized by using the alloys of this invention in the fabrication of structures required to withstand some particular level of operating stress. Conversely, in those instances where ultimate failure is attributable to stress rupture, the use of the alloy of the present invention would increase the time for failure by a factor of 10 as compared to the alloy of said patent.

The primary objective of the invention therefore, is to provide an alloy for heat resisting applications with significantly higher elevated temperature strength characteristics, specifically rupture strength, at temperatures up to about 2200° F., than alloys heretofore known.

Another object is to provide an alloy with high resistance to chemical deterioration at elevated temperatures in a variety of industrial environments.

A further object of this invention is to provide an alloy at relatively low cost possessing good hot workability which can be melted in air in an electric arc furnace using

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constituents and raw materials which are readily available and not strategic in nature.

A still further object of this invention is to provide a castable alloy possessing all of the desirable characteristics mentioned above.

Other aims and advantages of the invention will be apparent to those skilled in the art from the following description and appended claims.

In accordance with the present invention, an improved alloy is provided consisting essentially by weight of 35 to 55% nickel, 15 to 30% chromium, less than 6% each of molybdenum and tungsten either combined or separately, less than 5% cobalt, 0.001 to 0.10% boron, less than .12% nitrogen, up to 0.6% carbon with silicon and manganese not exceeding 2% each or 4% in total amount, the remainder being essentially iron. The impurities phosphorus and sulfur may each be present in amounts up to .025%.

The preferred range of essential constituents of this alloy in wrought form consists by weight of 44 to 47% nickel, 24 to 27% chromium, 2.50 to 4.0% each of the constituents molybdenum, tungsten and cobalt, .03 to .08% each of carbon and nitrogen, 0.005 to 0.05% boron, and 1.0 to 1.5% manganese and silicon, the remainder being essentially iron.

The preferred range of essential constituents of this alloy in cast form consists by weight of 44 to 47% nickel, 24 to 27% chromium, 2.5 to 4.0% each of the constituents molybdenum, tungsten and cobalt, .03 to .08% nitrogen, .015 to .050% boron, .25 to .35% carbon and 1.0 to 1.5% manganese and silicon, the remainder being essentially iron.

It has been discovered that the higher strength characteristics which distinguish the alloy of this invention from the prior art alloys can be consistently realized by carefully controlling the boron and nitrogen contents. Control of the nitrogen content is necessary to preserve the higher strength characteristics for, as it will be shown later, an increase in nitrogen content above about 0.10% actually results in a decrease in strength. This is an unexpected discovery for there are many references in the technical literature relative to the beneficial effects on strength of nitrogen additions. See, for example, the paper by A. Kasak, C. M. Hsiao and E. J. Dulis on "Relationships Between Composition and Properties of Austenitic Chromium - Manganese - Carbon - Nitrogen Stainless Steels" which appears in ASTM Proceedings, vol. 59, 1959, pp. 786 to 801, inclusive.

The alloys of the present invention also possess outstanding strength characteristics at temperatures up to 2200° F. in the form of castings. When the alloys are to be used in the cast condition, the carbon content is preferably increased to 0.6% maximum. This improves the castability of the alloys and affords some increase in high temperature strength with some sacrifice in room temperature ductility. Carbon contents greater than 0.6% produce a seriously embrittled alloy and do not further improve high temperature strength.

The advantages inherent in the alloys of this invention will become more apparent as the result of the discussion which follows.

The following Table I lists several typical heat resisting alloys which are widely used throughout industry. Alloy 333 is the improved alloy of Patent 2,955,934 above mentioned; whereas Alloys 330 and 600 are older prior art alloys. Alloy 600 is known to many as Inconel whereas

Alloy 330 is designated Incoloy 800 by a major producer of heat resisting alloys.

TABLE I.—TYPICAL HEAT RESISTING ALLOYS

Grade	C	Mn	Si	Ni	Cr	Fe	W	Mo	Co
300.....	.08	1.2	1.2	35.0	19.0	Bal.	-----	-----	-----
600.....	.08	0.6	0.3	Bal.	15.0	7.0	-----	-----	-----
333.....	.06	1.2	1.2	46.0	25.0	Bal.	3.0	3.0	3.0

Table II below lists some of the experimental alloys investigated in a study which lead to the discovery of the improved alloys of the present invention. All experimental alloys in the program were induction melted, cast into 100 pound ingot molds, press cogged and rolled to 5/8" square bars. The bars were solution annealed at 2200° F. for 30 minutes and water quenched.

TABLE II.—EXPERIMENTAL HEAT RESISTING ALLOYS

Alloy	C	Mn	Si	Ni	Cr	W	Mo	Co	Cb	B	N	Fe
2.....	.08	1.02	1.12	Bal.	25.79	3.14	3.15	3.46	Nil	Nil	.08	17.01
5.....	.07	1.06	1.15	Bal.	25.79	2.96	3.29	3.46	Nil	Nil	.12	16.07
6.....	.05	1.10	1.04	Bal.	25.90	2.76	3.32	3.35	Nil	Nil	.17	15.44
7.....	.06	1.03	1.15	Bal.	26.11	3.06	3.40	3.06	Nil	.05	.08	15.12
8.....	.05	.85	1.10	46.78	25.76	2.66	3.09	2.38	.24	.002	.05	Bal.
9.....	.06	.92	1.12	46.50	25.68	2.88	3.07	3.04	Nil	.002	.05	Bal.
10.....	.06	.93	1.12	46.40	25.76	2.90	2.97	3.10	Nil	.015	.05	Bal.
11.....	.05	.93	1.12	46.28	25.72	2.98	3.01	3.16	Nil	.045	.04	Bal.

Specimens for stress rupture tests were machined from the solution annealed material and were tested at temperatures of 1400, 1600 and 1800° F. Specimens from a production heat of the prior art 333 alloy in the solution annealed condition were included in the program to provide a base of reference.

The resulting data are summarized in Tables III to V, inc., below and the data thereof are plotted in the conventional manner in the accompanying drawings to obtain standard stress rupture charts which are designated FIGURES 1, 2 and 3. Table VI compares the 1000 hour rupture strength at 1400, 1600, 1800 and 2000° F. with typical values for the prior art alloys shown in Table I.

TABLE III.—RESULTS OF 1,600° F. STRESS-RUPTURE TESTS

Alloy	Variant	Stress, p.s.i.	Life, hr.	Percent El.	Percent RA
Typical 333...	None.....	12,000	18.7	22	24.4
		10,000	39.8	20	21.5
		9,000	64.2	16	18.2
		8,000	103.6	13	14.7
		6,000	282.4	10.5	12.2
2.....	.08 N.....	4,000	1,524.8	9.6	10.2
		10,000	45.7	14	9.6
		8,000	104.6	13	8.6
		10,000	29.0	5	3.2
		7,500	115.7	8	4.6
5.....	.12 N.....	10,000	20.3	12	10.4
		7,000	81.4	9	7.3
		12,000	74.4	27	29.6
		11,000	142.0	26	24.4
		7,715	693.9	16	13.3
6.....	.17 N.....	5,750	>1,450	-----	-----
		12,000	68.5	31	30
		10,000	146.2	28	27.7
		12,000	109	38	11.7
		10,000	223.4	37	47.9
10.....	.015 B.....	15,000	26.3	50	62.5
		12,000	95.6	50	53.5
		10,000	193.8	35	41.2
		7,000	873.7	16	14.7
		12,000	60.1	56	25.1
11.....	.05 B.....	10,000	135.4	41	9.6

TABLE IV.—RESULTS OF 1,800° F. STRESS-RUPTURE TESTS

Alloy	Variant	Stress, p.s.i.	Life, hr.	Percent El.	Percent RA
Typical 333...	None.....	6,000	8.8	30	26.5
		5,000	19.4	29	21.5
		4,000	103.6	27	19.4
		3,000	240.1	21	18.2
		2,000	1,548.7	16	12.5
8.....	.002 B, .24 Cb..	5,000	87.2	31	22.1
		4,000	396.1	22	17.3
9.....	.002 B, No Cb..	5,000	84.7	29.0	20.1
		4,000	228.6	19.0	10.3
10.....	.015 B.....	6,000	71.9	32.0	29.6
		5,000	128.4	25.0	26.5
11.....	.05 B.....	4,000	396.0	24.0	21.5
		5,000	150.2	29.0	32.4
		4,000	528.0	23.0	23.7

TABLE V.—RESULTS OF 1,400° F. STRESS-RUPTURE TESTS

Alloy	Variant	Stress, p.s.i.	Life, hr.	Percent El.	Percent RA
Typical 333...	None.....	25,000	12.5	53	41.4
		20,000	41.8	54	43.8
		15,000	162.0	45	39.7
		12,000	510.6	32	27.5
		20,000	82.1	35.0	28.3
8.....	.002 B, .24 Cb..	20,000	88.5	49.0	40.6
		25,000	50.3	62	63.5
9.....	.002 B.....	20,000	249.7	58	39.9
		16,000	1,402.8	30	30.6
10.....	.015 B.....	20,000	182.8	53	52.9

TABLE VI.—1000 HOUR RUPTURE STRENGTH, P.S.I.

Alloy	1,400° F.	1,600° F.	1,800° F.	2,000° F.
600.....	9,000	3,500	1,800	900
330.....	8,500	3,800	1,700	800
333.....	11,000	4,500	2,200	960
This Investigation.....	16,500	6,700	3,200	1,600

Several conclusions are evident from this data. The outstanding disclosure is that the alloys of this investigation are about 50% stronger than the best of the prior art alloys, namely the 333 alloy. This observation applies to the full temperature range from 1400 to at least 2000° F.

A careful study of the data in Tables III to V inclusive discloses that the improvement is attributable to the addition of .015% or more boron and to the limitation of nitrogen to .12% maximum. Note in Table III that alloys 2 and 5 containing .08 and .12% nitrogen, respectively, show essentially the same rupture life for a given level of stress as a typical alloy 333 heat whereas alloy 6 containing .17% nitrogen is clearly inferior.

Small additions of columbium are sometimes made to heat resisting alloys to improve their strength but a comparison of the data for alloys 8 and 9 in Table III shows an adverse effect of a columbium addition on the alloys of this invention.

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Although the data described above were obtained from the testing of wrought material having a carbon content of .08% maximum, similar beneficial effects result from the control of nitrogen in cast alloys of this invention together with the addition of boron in the ranges heretofore mentioned.

What is claimed is:

1. An alloy consisting essentially of about: 33-55% nickel, 15-30% chromium, less than 6% each of molybdenum and tungsten and combinations thereof, less than 5% of cobalt, less than 0.12% nitrogen, up to 0.6% carbon, up to 4% of metal of the group silicon and manganese but not exceeding 2% of each, 0.001-0.1% boron, phosphorus and sulfur not exceeding about 0.025% each, and the balance substantially all iron.

2. A forgeable alloy consisting essentially of about: 35-55% nickel, 15-30% chromium, less than 6% each of molybdenum and tungsten and combinations thereof, less than 5% cobalt, less than 0.12% nitrogen, up to 4% of metal of the group silicon and manganese but not exceeding 2% of each, phosphorus and sulfur not exceeding about 0.025% each, 0.001-0.1% boron, up to 0.1% carbon and the balance substantially all iron.

3. A cast alloy consisting essentially of about: 44-47% nickel, 24-27% chromium, 2.5-4% each of molybdenum, tungsten and cobalt, 0.03-0.08% nitrogen, 0.015-

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0.05% boron, 0.25-0.35% carbon, 1 to 1.5% of metal of the group manganese and silicon, and the balance substantially all iron.

4. A forgeable alloy consisting essentially of about: 44-47% nickel, 24-27% chromium, 2.5-4% each of molybdenum, tungsten and cobalt, 0.03-0.08% each of carbon and nitrogen and combinations thereof, 0.005 to 0.05% boron, and the balance substantially all iron.

5. A forgeable alloy consisting essentially of about: 44-47% nickel, 24-27% chromium, 2.5-4% each of molybdenum, tungsten and cobalt, 0.03-0.08% carbon, up to 0.08% nitrogen, 0.005-0.05% boron, 1-1.5% of manganese and silicon and combinations thereof, balance substantially all iron.

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