

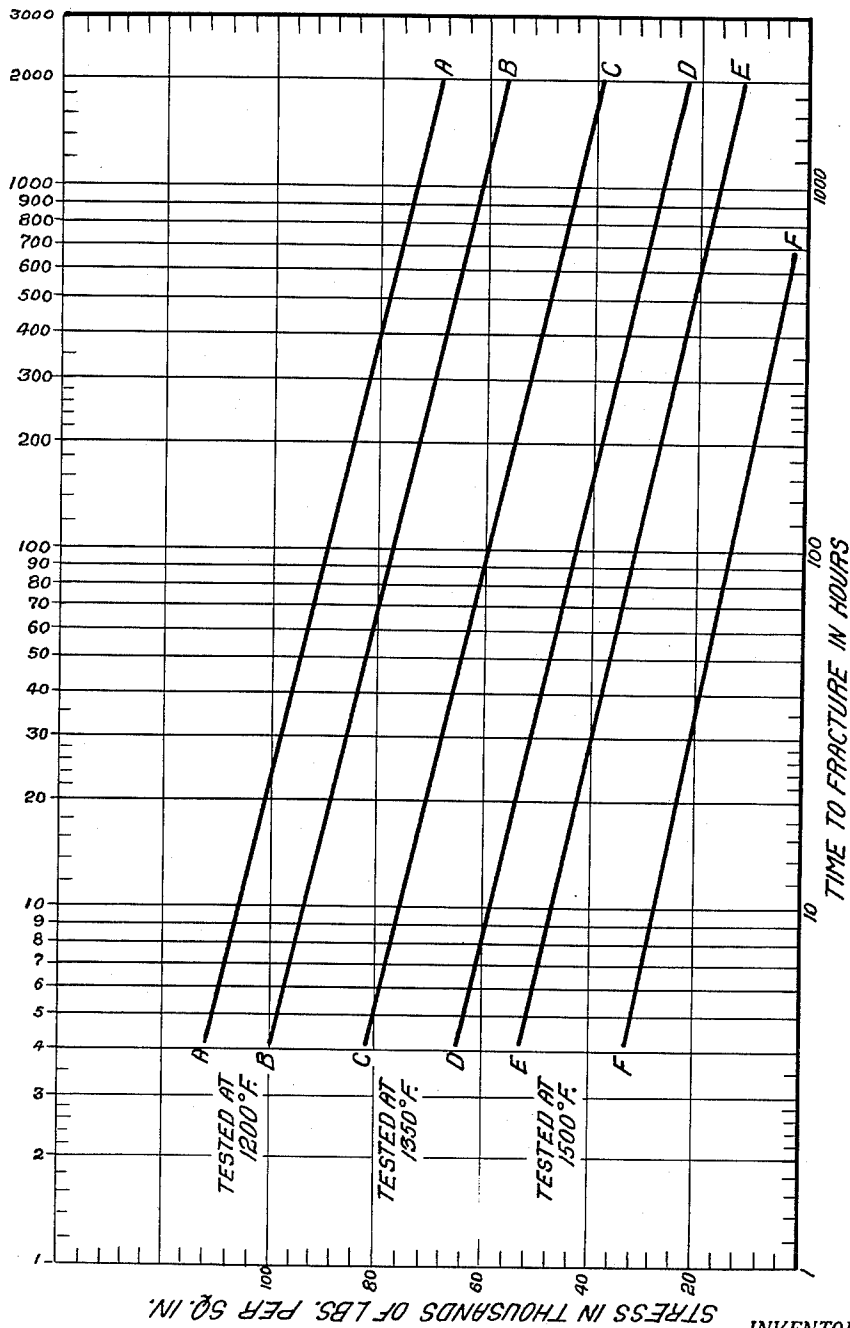
Aug. 7, 1962

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3,048,485

HIGH STRENGTH CREEP RESISTING ALLOY

Filed March 14, 1955



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3,048,485
HIGH STRENGTH CREEP RESISTING ALLOY
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Filed Mar. 14, 1955, Ser. No. 493,923
6 Claims. (Cl. 75-128)

The present invention relates to alloys particularly suitable for use at elevated temperatures and, more particularly, to improved alloys containing nickel, iron and chromium and having an unusual combination of properties, including high rupture strength and creep resistance together with good ductility at elevated temperatures.

The art has endeavored to develop alloys having a satisfactory rupture strength and high resistance to creep over extended periods of time at high temperatures, for example, in the temperature range from about 600° F. to 1500° F., for use in gas turbines, jet engines and other applications requiring high creep resistance and rupture strength in this temperature range. However, the service requirements of the various pieces of equipment have been steadily increasing and the industry is now looking for even stronger alloys than heretofore used.

It has now been discovered that when alloys containing nickel, iron and chromium also contain a particular combination of elements cooperating with each other in special ranges, they can be given high solution temperature heat treatments without encountering brittleness or notch sensitivity and resulting in very high creep resistance and rupture strength properties in the temperature range from about 600° F. to 1500° F. and higher.

It is an object of the present invention to provide an alloy containing nickel, iron and chromium and having a very high rupture strength in the temperature range from about 600° F. to about 1500° F.

Another object of the invention is to provide an alloy containing nickel, iron and chromium and having high creep and rupture strengths at elevated temperatures together with good ductility through the entire range from room temperature up to about 1500° F. and higher.

The invention also contemplates providing an article subjected in use to high stresses at high temperatures and made of a nickel-iron-chromium alloy having high creep and rupture strengths at elevated temperatures together with good ductility through the entire range from room temperature up to about 1500° F. and higher.

It is a further object of the invention to provide a nickel-iron-chromium alloy of low strategic alloying content for applications requiring high strength at all temperatures up to approximately 1500° F., which alloy is substantially free from notch sensitivity in the foregoing temperature range.

The invention further contemplates providing a nickel-iron-chromium alloy substantially free from strategically scarce ingredients, such as columbium, cobalt, and tungsten, for applications requiring high strength at elevated temperatures of approximately 600° F. to 1500° F. and higher.

Other objects and advantages will become apparent from the following description taken in conjunction with the accompanying drawing which is a graph plotting stress against time-to-rupture for alloys embodying the invention in various heat-treated conditions.

Generally speaking, the present invention contemplates providing a nickel-iron-chromium alloy having a low strategic alloying content and having high creep resistance and rupture strength together with substantial freedom from notch sensitivity at high temperatures such as from about 600° F. to about 1500° F. as well as having good

ductility throughout the entire range from room or atmospheric temperatures up to about 1500° F. In general, the nickel-iron-chromium alloy composition having the aforementioned characteristics can contain from about 25% to 50% nickel, preferably at least about 34% nickel, about 8% to 25% chromium, about 1.5% to 6% titanium, about 2% to 8% molybdenum, about 0.01% to 0.3% boron, together with up to about 2% aluminum, up to about 0.3% carbon, up to about 3% manganese, up to about 1% silicon, up to about 1% vanadium, up to about 0.5% tungsten, up to about 5% copper, and the balance essentially iron. The alloys in all cases will contain less than about 50% iron and more than 10%. Departure from the foregoing ranges of the composition leads to loss of ductility and/or creep and rupture resistance.

In carrying the invention into practice, it is generally preferred that the composition be maintained within the following ranges:

TABLE I

	Percent
Nickel -----	About 34 to 45
Chromium -----	About 12 to 16
Titanium -----	About 2 to 3
Molybdenum -----	About 5 to 7
Boron -----	About 0.03 to 0.15
Aluminum -----	Up to about 0.75
Carbon -----	Up to about 0.2
Manganese -----	Up to about 1
Silicon -----	Up to about 0.5
Copper -----	Up to about 3
Balance essentially iron.	

Moreover, under certain conditions it may be desirable to maintain the nickel within the range of about 40% to 45%.

When it is stated that the balance is essentially iron, it is to be understood that the balance will be substantially all iron but it can contain small amounts of other elements which do not affect the basic character of the composition or its behavior in use. For example, in commercial alloys embodying the present invention, the balance may include besides iron other agents and incidental impurities such as indicated in my prior U.S. Patent No. 2,150,094 or in the U.S. patent to Kayes No. 2,150,095. Usually the total amount of these elements is very small and is usually about 1% or less. As nickel usually contains a small amount of cobalt in association therewith, it is understood that the balance includes cobalt in incidental amounts, e.g., up to about 1%. The balance, of course, includes incidental impurities such as sulfur, phosphorus, etc., which are kept as low as is commercially practicable. Sulfur generally should be below about 0.05% and preferably not in excess of about 0.03%. Phosphorus preferably should not exceed about 0.03%. Calcium in large amounts is an undesirable impurity, but residual traces may have a beneficial effect.

The high temperature properties of the alloys embodying the present invention may be developed by a high temperature heat treatment which may comprise a high temperature solution treatment followed by an aging treatment at lower temperatures. For high resistance to notch sensitivity, the high temperature solution treatment preferably comprises heating the alloys within the range of about 2000° F. to about 2150° F. for at least about 0.1 and up to about 8 hours, followed by rapid cooling. When lower solution temperatures down to 1800° F., such as about 1875° F., are employed, the notch sensitivity of the subsequently aged alloy is usually increased and the rupture life of even the unnotched specimen is usually decreased. In this respect, the alloy behaves differently from prior alloys in which the oppo-

site is usually true, i.e., low solution temperatures, such as 1800° F. to 1875° F., produced substantial freedom from notch sensitivity whereas high solution temperatures, such as 2000° F. to 2050° F., induced notch sensitivity. The alloys are then subjected to an aging treatment which comprises reheating within the range of about 1100° F. to 1500° F. for a sufficient time which is usually longer the lower the aging temperature. Satisfactory aging is obtained by reheating for about one-half to 80 hours or longer, the longer aging treatments being employed in conjunction with the lower aging temperatures. The aging treatment is preferably carried out within the range

ment would be omitted in accordance with either of the previously described heat treatments is the instance of formed sheet or strip which is to be fabricated into assemblies. In such a case, a satisfactory heat treatment may comprise aging the hot or cold worked sheet or strip or the annealed sheet or strip at about 1350° F. to about 1450° F. for about ½ to 4 hours.

The improved results obtained by the present invention when the composition contains nickel, chromium, iron, titanium, molybdenum and boron within the foregoing ranges are illustrated by data obtained on the following alloys:

TABLE II

Elements	Percentages by Weight						
	Alloy 1	Alloy 2	Alloy 3	Alloy 4	Alloy 5	Alloy 6	Alloy 7
Nickel.....	43.9	34.4	36.6	41.8	31.5	32.5	31.4
Chromium.....	12.7	14.1	14.6	13.1	16.4	15.4	16
Titanium.....	2.41	2.47	2.73	2.41	2.48	2.39	2.33
Molybdenum.....	5.7	5.7	6.1	5.4	2.8	0	0.33
Boron.....	¹ >0.07	¹ >0.07	¹ >0.07	¹ >0.07	¹ >0.07	¹ >0.07	Trace
Aluminum.....	0.13	0.14	0.67	0.16	0.21	0.24	0.13
Carbon.....	0.04	0.05	0.07	0.07	0.06	0.11	0.05
Manganese.....	0.5	0.5	0.6	0.6	0.5	0.5	0.1
Silicon.....	0.23	0.11	0.16	0.16	0.13	0.18	0.15
Copper.....	0.03	0.04	0.02	0.02	0.04	0.07	0.05
Sulfur.....	0.01	0.007	0.003	0.006	0.008	0.009	0.007
Iron.....	(²)	(²)	(²)	(²)	(²)	(²)	(²)

¹ 0.10% boron was added.

² The balance of each of the alloys in Table II is essentially iron.

of about 1200° F. to about 1300° F. or 1325° F. for about 1 to about 48 hours. The alloys may then be cooled in any desired manner. As will be apparent to those skilled in the art, the aging treatment may comprise more than one reheating operation. In fact, optimum room temperature properties can be obtained in an alloy which has been previously solution treated by employing a double aging treatment. The double aging treatment may advantageously comprise holding the alloy for about 16 to 24 hours at approximately 1300° F. followed by a treatment for about 16 to 24 hours at around 1200° F. However, where the high temperature properties are important but the room temperature properties do not need to be the very maximum, then, rather than using the dual aging treatment, a single aging treatment of about 16 to 24 hours at approximately 1300° F. is sufficient after the solution treatment. Under certain circumstances, an intermediate or pre-aging treatment may be employed between the high temperature solution treatment and the aging treatment. Such an intermediate or pre-aging treatment can be conducted within the range of about 1500° F. to 1750° F., e.g., about 1550° F. or 1650° F., for about 1 to 24 hours. The high temperature treatment may be carried out simultaneously with other operations. Thus, when the finishing temperature after hot working (for example, after forging) is high and is within or near the ranges set forth herein for the solution treatment, it is possible to combine the solution treatment with a hot working operation. Such a procedure would retain most of the benefits achieved by a solution treatment and, in addition, would have the advantage of imparting somewhat higher room temperature properties after aging. In other cases where the room temperature strength is more important than the high temperature strength, the solution treatment may be omitted as good properties may be developed by forging or otherwise hot or cold working the alloys and then aging them by any of the foregoing aging treatments without a preliminary solution heat treatment. In still another case where the room temperature strength is important but must be combined with good forming properties, the hot or cold worked alloy can be annealed, e.g., for 5 to 10 minutes or longer at 1850° F. to 1950° F., and then aged. An example where the solution treat-

Alloys Nos. 1 to 5, inclusive, have compositions in accordance with the invention and alloys Nos. 1 to 4 have compositions within the preferred ranges of the elements of Table I. Alloys Nos. 6 and 7 have compositions outside the scope of the invention and are included for comparison purposes. Portions of the foregoing alloys of Table II were subjected to various heat treatments. Some of the portions were subjected to a solution treatment for four hours at 1875° F. Other portions were given solution heat treatments at 2050° F. and 2150° F., respectively, for two hours. After their respective solution heat treatments, all portions were oil quenched and then given an aging treatment for 20 hours at 1300° F., followed by 20 hours at 1200° F. before testing. The foregoing heat treatments, involving solution treatments at 1875° F., 2050° F., and 2150° F., will hereinafter be designated as "H-1," "H-2," and "H-3," respectively. The heat-treated alloys were then tested under various stresses at 1200° F., 1350° F. and 1500° F., respectively, to determine their time to fracture and their percentage elongation. The results of these tests are set forth in Table III.

TABLE III

Heat Treatment	Tested at		Time to Fracture, Hrs.	Percent Elongation
	° F.	Stress, p.s.i.		
ALLOY NO. 1				
H-2.....	1,000	120,000	431.8	5.0
H-2.....	1,200	100,000	6.1	8.5
H-2.....	1,200	90,000	34.3	7.5
H-2.....	1,200	80,000	106.7	8.5
H-2.....	1,200	75,000	217.6	6.5
H-2.....	1,200	70,000	396.3	8.0
H-2.....	1,200	60,000	1,698.8	8.5
II-2.....	1,350	70,000	5.8	19.0
H-2.....	1,350	60,000	22.0	18.5
H-2.....	1,350	50,000	79.5	19.0
H-2.....	1,350	40,000	266.6	19.0
H-2.....	1,350	20,000	1,293.3	26.5
H-2.....	1,500	30,000	17.6	31.5
H-2.....	1,500	25,000	36.5	33.5
H-2.....	1,500	20,000	90.1	37.5
H-2.....	1,500	15,000	288.8	43.5

TABLE III—Continued

Heat Treatment	Tested at		Time to Fracture, Hrs.	Percent Elongation
	° F.	Stress, p.s.i.		
ALLOY NO. 2				
H-1.....	1,200	100,000	6.2	9.0
H-1.....	1,200	90,000	22.6	7.5
H-1.....	1,200	80,000	67.5	3.5
H-1.....	1,200	80,000	67.5	4.0
H-1.....	1,200	80,000	166.7	4.0
H-1.....	1,200	70,000	379.0	4.0
H-1.....	1,350	60,000	16.9	17.5
H-1.....	1,350	50,000	73.1	20.0
H-1.....	1,350	45,000	130.3	14.0
H-2.....	1,200	100,000	15.6	14.0
H-2.....	1,200	90,000	77.5	13.5
H-2.....	1,200	80,000	168	8.0
H-2.....	1,200	80,000	315.6	8.0
H-2.....	1,200	80,000	360+	(?)
H-2.....	1,200	75,000	462.9	9.0
H-2.....	1,350	70,000	7.9	21.0
H-2.....	1,350	60,000	29.2	19.0
H-2.....	1,350	50,000	135.3	17.5
H-2.....	1,350	45,000	249.3	19.0
H-2.....	1,350	40,000	402.0	20.0
H-2.....	1,500	25,000	46.9	35.0
H-2.....	1,500	20,000	137	38.5
H-3.....	1,350	50,000	323.6	16.0
H-3.....	1,500	25,000	80.4	33.5
ALLOY NO. 3				
H-2.....	1,200	90,000	85.1	5.0
H-2.....	1,200	80,000	346.7	2.5
H-2.....	1,350	50,000	211.5	10.0
H-3.....	1,350	50,000	228.7	7.5
H-2.....	1,500	25,000	197.0	29.0
H-2.....	1,500	30,000	75.1	21.0
H-3.....	1,500	25,000	258.3	23.5
H-3.....	1,500	30,000	112.4	11.5
ALLOY NO. 4				
H-2.....	1,200	90,000	20.1	7.5
H-2.....	1,350	50,000	65.3	16.0
H-2.....	1,500	25,000	34.5	31.5
ALLOY NO. 5				
H-1.....	1,200	100,000	6.2	13.5
H-1.....	1,200	90,000	29.2	11.5
H-1.....	1,200	80,000	94.1	4.0
H-1.....	1,350	60,000	12.7	19.0
H-1.....	1,350	50,000	32.8	13.5
H-1.....	1,350	45,000	73.2	19
H-1.....	1,350	40,000	144.5	15.5
H-2.....	1,200	100,000	4.8	11.0
H-2.....	1,200	90,000	27.1	6.5
H-2.....	1,200	80,000	132.2	6.5
H-2.....	1,200	70,000	450+	-----
H-2.....	1,350	60,000	30.3	28.5
H-2.....	1,350	50,000	76.1	17.5
H-2.....	1,350	45,000	162.6	14.0
H-2.....	1,350	40,000	297.9	19.0
H-2.....	1,500	20,000	67.5	38.5
H-1.....	1,500	20,000	29.5	-----
ALLOY NO. 6				
H-1.....	1,200	80,000	2.5	4.0
H-1.....	1,200	60,000	22.0	2.5
H-1.....	1,350	45,000	8.5	6.0
H-2.....	1,200	80,000	16.0	10.0
H-2.....	1,200	80,000	17.5	8.0
H-2.....	1,200	60,000	308.9	6.0
H-2.....	1,350	45,000	35.1	10.5
H-2.....	1,350	45,000	46.9	11.5
ALLOY NO. 7				
H-1.....	1,200	80,000	1.3	3.0
H-1.....	1,200	60,000	85.8	2.5
H-1.....	1,350	45,000	30.9	4.0
H-2.....	1,200	80,000	1.6	5.0
H-2.....	1,200	70,000	66.9	4.0
H-2.....	1,200	60,000	2360	-----
H-2.....	1,350	45,000	149.3	9.0

¹ Notched.² Unbroken.

The foregoing tests reported in Table III are illustrative of the high rupture strength and ductility at high temperatures of the new alloys provided by this invention. When the composition is according to the invention as illustrated by alloys Nos. 1 to 5, the alloys exhibit

much longer fracture lives for a given load and withstand much higher loads for a given life than alloys of similar composition, as illustrated by alloys Nos. 6 and 7 which do not contain the combination of special elements in the amounts set forth hereinbefore. The foregoing tests also confirm that the present alloys are not notch sensitive when they are solution treated at high temperatures in the vicinity of 2050° F.

Portions of alloy No. 2 of Table II, heat treated by procedures H-1 and H-2 as described in connection with the tests reported in Table III, were subjected to various room temperature tensile tests. The results of these tests, showing the excellent room temperature characteristics of the new alloy, are reported in Table IV.

TABLE IV

	H.T. H-2	H.T. H-1
Proportional Limit, p.s.i.....	46,000	46,500
Proof Stress, p.s.i.....	68,000	61,000
0.2% Yield Strength, p.s.i.....	117,000	120,000
Tensile Strength, p.s.i.....	175,000	181,000
Percent Elongation.....	21.4	21.4
Percent Reduction in Area.....	34.8	38.0

Hot rolled bars of alloy No. 1 of Table II were subjected to heat treatment H-2. Tensile tests were then made on these bars and the results are reported in Table V.

TABLE V

Test. Temp., ° F.	0.2% Yield Strength, p.s.i.	Tensile Strength, p.s.i.	Percent Elongation	Percent Reduction of Area
80.....	114,500	174,500	19	30.9
1,000.....	101,500	145,000	19	35.7
1,100.....	101,000	144,000	20	33.5
1,200.....	93,500	135,000	20	29.5
1,300.....	89,500	115,000	18	-----
1,400.....	78,500	90,000	18	-----
1,500.....	57,500	69,000	43.4	-----

The foregoing data reported in Table V indicate that the new alloy of this invention possesses remarkably high strength combined with good ductility throughout the entire range from room temperature up to 1500° F. For example, Table V shows a series of tests in which the 0.2% yield strength is about 100,000 p.s.i. at 1000° F. to 1200° F. These are most unusual properties and are about 10,000 p.s.i. stronger than the best competitive alloy. Young's modulus shows the same trend for the new alloy, being substantially higher than the best competitive alloy in the 1000° F. to 1200° F. temperature range. The new alloys may even be advantageously employed at sub-zero temperatures.

Alloys of the present invention withstand extrusion and hot rolling without difficulty. For example, billets from melts of alloys Nos. 1, 2 and 5 of Table I were heated to 1950° F. and extruded to a 3/4 inch diameter round rod, while another billet from each melt was heated to 2000° F. and extruded to 2 7/8 inch diameter round rod. These rods were machined to about 3 inch and about 2 3/4 inch diameter, respectively, heated to 2000° F. and hot rolled to a 5/8 inch square rod for test purposes. The hot malleable ranges for these alloys, as determined by hot bend tests, are given in Table VI.

TABLE VI
Hot Bend Tests

Alloy No.:	Hot bend range
1.....	1700-2200° F. inclusive
2.....	1700-2150° F. inclusive
5.....	1700-2150° F. inclusive

Some of the advantages of the present invention are illustrated in Table VIII. This table gives the approximate stresses required to produce rupture in 100 hours as well as the elongation for the heat treated alloy No. 2 of Table II in comparison with typical published properties for the variously heat treated known alloys of Table

VII. The data reported in Table VIII illustrate the excellent 100 hour rupture strength combined with good ductility of the alloy of this invention in comparison with the various known alloys of Table VII.

TABLE VII

Elements	Alloy A	Alloy B	Alloy C	Alloy D	Alloy E
Carbon.....	0.09	0.10	0.02	1 0.08	0.03
Manganese.....	1.76	1.33	1.38	1.25	0.50
Silicon.....	0.42	0.76	1.0	0.7	0.30
Chromium.....	15.8	16.3	13.5	14.75	15.0
Nickel.....	25.3	25.5	26.2	26	73.0
Molybdenum.....	6.4	6.35	3.01	1.25	-----
Columbium.....	-----	-----	-----	-----	0.6
Titanium.....	-----	-----	1.61	2.1	2.4
Aluminum.....	-----	-----	0.11	10.35	0.9
Vanadium.....	-----	-----	-----	0.25	-----
Iron.....	Bal.	Bal.	Bal.	Bal.	7.0

¹ Maximum amount.

TABLE VIII

Alloy	100 Hour Rupture Life			
	at 1,200° F.		at 1,350° F.	
	stress, 1,000 p.s.i.	Elongation (Estimated) percent	stress, 1,000 p.s.i.	Elongation (Estimated) percent
2 (H.T. H-2).....	88	12.5	52	18
A.....	50	10	28	17
B.....	35	6.2	25	6
C.....	55.5	4	32	7.5
D.....	61	-----	35	-----
E.....	80	-----	50	3

The high rupture strength characteristics of the new heat treated alloys Nos. 1 to 5 of Table II are illustrated in the stress versus time-to-rupture curves of the drawing. On the drawing the time-to-fracture lives of these heat treated alloys at various stresses lie substantially in the band between curves A—A and B—B when tested at 1200° F., in the band between curves C—C and D—D when tested at 1350° F., and in the band between curves E—E and F—F when tested at 1500° F. The stress versus time-to-rupture values for the alloys heat treated in accordance with heat treatment procedure H-1 generally lie near the lower curves B—B, D—D and F—F. As the solution heating temperature is increased, as with heat treatment procedures H-2 and H-3, the respective stress versus time-to-rupture values fall nearer to the upper curves A—A, C—C and E—E.

Further advantages of the new alloys are their high fatigue strength or endurance limit at elevated temperatures. The new alloys also have very good room temperature tensile properties. For example, alloys included within this invention may have a minimum tensile strength of at least about 150,000 p.s.i. The foregoing tensile strength is that of the alloy after heat treatment H-2 which thoroughly anneals the alloy before the aging treatment. If the solution treatment is carried out at a lower temperature or is omitted, the room temperature strength properties are appreciably higher. For example, a sample from alloy No. 1 was forged at about 2000° F. and then directly aged for 16 hours at 1300° F. without any solution treatment. When tested at room temperature, the yield strength (at 0.2% offset) of the material was 138,000 p.s.i. while the tensile strength was 180,000 p.s.i. and the elongation was 19.5%.

By employing the novel combination of elements within the composition range contemplated by the present invention, the alloys when heat treated in accordance with the aforementioned procedure possess a fine grain which is highly desirable to avoid notch sensitivity and for resistance to thermal shock. In prior alloys, great care had to be taken to forge and heat treat within narrow ranges which resulted in lower properties. However, by employing the new combination of ingredients in special ranges, it has been found that the alloy is relatively insensitive to forging temperatures and may be solution treated at com-

paratively high temperatures which produce very high rupture strength without encountering notch sensitivity. The alloy contemplated by the present invention exhibits higher strength in the presence of notches than prior alloys of comparable strength. This has been confirmed by tests on specimens (0.357 inch diameter) in which the notch is a 60 degree V-notch with the cross-sectional area at the root of the V approximately one-half the cross-sectional area of the full section of the specimen and with the curvature at the root of the notch having a radius of 0.005 inch. Other test specimens with the same notch concentrations factor can, of course, be used to confirm the improved strength of the alloy in the presence of notches.

The present invention is particularly applicable to parts for use in gas turbines, jet engines and other applications requiring high creep and rupture strengths in the temperature range from about 600° F. to about 1500° F. The combination of high properties obtainable by the invention makes the alloy suitable for a wide variety of articles subjected to load at elevated temperatures and/or at atmospheric temperatures. These alloys are particularly suitable for small sections such as second or third stage turbine blades, and particularly hollow turbine blades, high temperature bolts, fittings, etc. These alloys also may be fabricated into large sections such as turbine rotors with better properties than the alloys now being used for this application. The new alloys may also be used for plates, sheets, strips, rods, wires, bars, tubing, forgings, stampings, extrusions, castings, parts of steam turbines, gas turbines (including superchargers), jet propulsion engines, etc., such as moving or stationary turbine blades, buckets and nozzles (including precision cast buckets, etc.), turbine rotors, turbine wheels, turbine bolts, combustion chambers or flame tubes, tail cones, afterburner parts, shrouding, bellows, etc.; parts of internal combustion engines, such as valves, valve seats, valve springs, etc.; parts of machines and apparatus operating at elevated temperatures, such as springs, extrusion dies, mandrels, piercer points, dummies (for extrusion presses), dies and anvils for forging and drop forging, cutters for hot metal, furnace parts, large searchlight reflectors, etc.; supports and elements in radio tubes, incandescent lamps, electronic tubes, etc.; springs operating at elevated temperatures and/or atmospheric temperatures, including valve springs, springs in automatic rifles, springs in torpedoes, springs in measuring and indicating instruments, etc.; bolts, music wire, armature binding wire, bicycle spokes and other wire products; metallic mirrors and reflectors; etc. One of the important uses of the new alloy is the production of sheet and strip and products made therefrom.

It is to be observed that the present invention provides as an article of manufacture a structural element which in normal use requires high creep and rupture strengths combined with good ductility both at room temperature and at high temperatures.

Furthermore, the present invention provides an alloy having very high creep resistance and rupture strength together with substantial freedom from notch sensitivity at elevated temperatures as well as having good ductility at temperatures including room temperature and up to very high temperatures and particularly suitable for hollow and solid turbine blades and other parts of machines operating at elevated temperatures.

Moreover, the present invention provides a creep and oxidation-resistant, high temperature alloy comprising about 34% to 45% nickel, about 12% to 16% chromium, about 2% to 3% titanium, about 0.03% to 0.15% boron, about 5% to 7% molybdenum, and about 47% to 23% iron and having an unusual combination of high rupture strength and high ductility together with insensitivity to notch. The high ductility embraces a minimum elongation of about 5% in the unnotched specimens. The high rupture strength usually embraces rupture lives in both the notched and unnotched specimens in excess of about

100 hours at 1200° F. under a stress of about 80,000 p.s.i. and in excess of about 25 hours at 1200° F. under a stress of about 90,000 p.s.i. The high rupture strength always embraces rupture lives in both the notched and the unnotched specimens in excess of about 100 hours at 1200° F. under a stress of about 70,000 p.s.i. and in excess of about 25 hours at 1200° F. under a stress of about 80,000 p.s.i.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

I claim:

1. A heat-resisting, age-hardenable alloy suitable for use in the form of notched and unnotched gas turbine structures at temperatures ranging up to about 1500° F. under high stress which contains about 34% to about 45% nickel, about 12% to about 16% chromium, about 2% to about 3% titanium, about 5% to about 7% molybdenum, about 0.03% to about 0.15% boron, up to about 0.75% aluminum, up to about 0.2% carbon, up to about 1% manganese, up to about 0.5% silicon, up to about 3% copper and the balance essentially iron and characterized in the heat treated condition resulting from aging from the solution treated condition for about one-half to about 80 hours at a temperature of about 1100° F. to about 1500° F. by a life-to-rupture at least in excess of about 100 hours when tested at 1200° F. under a stress of 70,000 pounds per square inch and a life-to-rupture at least in excess of 25 hours when tested at 1200° F. under a stress of 80,000 pounds per square inch.

2. A heat-resisting, age-hardenable alloy suitable for use in the form of notched and unnotched gas turbine structures at temperatures ranging up to about 1500° F. under high stress which contains about 34.4% to about 43.9% nickel, about 12.7% to about 14.6% chromium, about 5.4% to about 6.1% molybdenum, about 2.41% to about 2.73% titanium, about 0.13% to about 0.67% aluminum, about 0.07% boron, about 0.04% to about 0.07% carbon, about 0.5% to about 0.6% manganese, about 0.11% to about 0.23% silicon, the balance essentially iron together with incidental amounts of impurities and elements normally associated therewith and characterized in the heat-treated condition resulting from solution treatment at a temperature in the vicinity of 2050° F. and thereafter aging for about 20 hours at a temperature of about 1300° F. and for about 20 hours at a temperature of about 1200° F. by a life-to-rupture at least in excess of about 100 hours when tested at 1200° F. under a stress of 80,000 pounds per square inch and a life-to-rupture at least in excess of about 65 hours when tested at 1350° F. under a stress of 50,000 pounds per square inch.

3. An article subjected in use to severe stress at elevated temperatures of about 1000° F. to 1500° F. and comprised of an age-hardened alloy having high rupture strength in the foregoing temperature range combined with good ductility and substantial freedom from notch sensitivity at all temperatures up to about 1500° F., said alloy containing about 34% to 45% nickel, about 12% to 16% chromium, about 2% to 3% titanium, about 5% to 7% molybdenum, about 0.03% to 0.15% boron, up to about 0.75% aluminum, up to about 0.2% carbon, up to about 1% manganese, up to about 0.5% silicon, up

to about 3% copper, and the balance essentially iron; said alloy being aged from the solution treated condition for about one-half to about 80 hours at a temperature of about 1100° F. to about 1500° F. to provide a life-to-rupture at least in excess of about 100 hours when tested at 1200° F. under a stress of 70,000 pounds per square inch and a life-to-rupture at least in excess of 25 hours when tested at 1200° F. under a stress of 80,000 pounds per square inch.

4. An article subjected in use to severe stress at elevated temperatures of about 1000° F. to 1500° F. and comprised of an age-hardened alloy having high rupture strength in the foregoing temperature range combined with good ductility and substantial freedom from notch sensitivity at all temperatures up to about 1500° F., said alloy containing about 34.4% to about 43.9% nickel, about 12.7% to about 14.6% chromium, about 5.4% to about 6.1% molybdenum, about 2.41% to about 2.73% titanium, about 0.13% to about 0.67% aluminum, about 0.7% boron, about 0.4% to about 0.07% carbon, about 0.5% to about 0.6% manganese, about 0.11% to about 0.23% silicon, the balance essentially iron together with incidental amounts of impurities and elements normally associated therewith; said alloy being in the heat-treated condition resulting from solution treatment at a temperature in the vicinity of 2050° F. and thereafter aging for about 20 hours at a temperature of about 1300° F. and for about 20 hours at a temperature of about 1200° F. by a life-to-rupture at least in excess of about 100 hours when tested at 1200° F. under a stress of 80,000 pounds per square inch and a life-to-rupture at least in excess of about 65 hours when tested at 1350° F. under a stress of 50,000 pounds per square inch.

5. A heat-resisting, age-hardenable alloy suitable for use in the form of notched and unnotched gas turbine structures at temperatures ranging up to about 1500° F. under high stress which contains about 34% to about 45% nickel, about 12% to about 16% chromium, about 2% to about 3% titanium, about 5% to about 7% molybdenum, a small but effective amount up to about 0.15% boron, up to about 0.75% aluminum, up to about 0.2% carbon, up to about 1% manganese, up to about 0.5% silicon, up to about 3% copper and the balance essentially iron and characterized in the heat-treated condition resulting from aging from the solution treated condition for about one-half to about 80 hours at a temperature of about 1100° F. to about 1500° F. by a life-to-rupture at least in excess of about 100 hours when tested at 1200° F. under a stress of 70,000 pounds per square inch and a life-to-rupture at least in excess of 25 hours when tested at 1200° F. under a stress of 80,000 pounds per square inch.

6. An iron-nickel-chromium alloy consisting essentially of 34% to 50% nickel, 8% to 25% chromium, 1.5% to 6% titanium, 2% to 8% molybdenum, 0.01% to 0.3% boron, up to 2% aluminum, up to 0.3% carbon, up to 3% manganese, up to 1% silicon, up to 1% vanadium, up to 0.5% tungsten, up to 5% copper, and the balance essentially iron with the iron content being more than 10% and less than 50% of the alloy.

References Cited in the file of this patent

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,048,485

August 7, 1962

Clarence G. Bieber

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

Column 1, line 67, for "nickel- iron- chromium" read -- nickel-iron-chromium --; column 4, line 3, before "fabricated" insert -- be --; same column 4, TABLE II, under the heading "Elements", line 2 thereof, for "Chrominum" read -- Chromium --; column 5, TABLE III, for sub-heading "ALEOY NO. 7" read -- ALLOY NO. 7 --; column 10, line 20, for "0.7% boron, about 0.4%" read -- 0.07% boron, about 0.04% --.

Signed and sealed this 7th day of July 1964.

(SEAL)

Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents