United States Patent Office

2,765,226

Patented Oct. 2, 1956

2,765,226

HIGH TEMPERATURE ALLOY

James D. Nisbet, Pittsburgh, Pa., assignor to General Electric Company, a corporation of New York

No Drawing. Application December 24, 1953, Serial No. 400,379

6 Claims. (Cl. 75—134)

This invention relates to alloys which have high strength at elevated temperatures, particularly at about 1500° F., and wrought structural articles made from such an alloy.

The development of the gas turbine and similar devices has created a demand for materials which have high mechanical properties as well as dimensional and physico-chemical stability under high stress at temperatures up to 1500° F. Because of the uses to which these alloys are frequently put, it is essential that they be capable of withstanding these high stresses at high temperatures for long periods of time.

Many of the known alloys which have acceptable mechanical properties at elevated temperatures require casting techniques and can be forged, rolled, or machined only with great difficulty. Therefore, articles which must be manufactured within close dimensional tolerances from these alloys are restricted by practical considerations to expensive precision casting methods. It is, therefore, obvious that a wrought alloy having the required properties would permit more economical mass production methods to be used and result in a better and cheaper product.

All of the previously known wrought alloys (i. e., alloys which permit economical, conventional forming operations such as forging, drawing, etc.) which also have acceptable high temperature properties, incorporate either high percentages of cobalt, nickel, molybdenum and tungsten, and/or include substantial portions of such rare and expensive elements as niobium and tantalum. In view of the fact that all of the above-mentioned elements may be classified as "strategic" materials, and therefore, their availability and cost may be subject to controls other than the law of supply and demand, it is of importance that this invention provides a wrought alloy having mechanical properties comparable with or superior to any known commercially available high temperature wrought alloy without depending upon excessively high percentages of cobalt, chromium, nickel, molybdenum or tungsten, and without such elements as niobium, vanadium and tantalum.

It is a principal object of this invention to provide an alloy having high strength at elevated temperatures which

is both chemically and physically stable under high temperature and stress and which is readily fabricated by the usual methods of forging, rolling and machining.

It is a further object of this invention to provide wrought articles made from a new alloy which will withstand stresses at 1500° F. of substantially the same magnitude as similar wrought articles made of known alloys at 1500° F. without depending upon excessively large amounts of strategic metals.

The alloy forming the subject matter of this invention contains essentially 18 to 22% iron, 18 to 22% cobalt, 26 to 30% nickel, 18 to 22% chromium, 6 to 7.5% tungsten, 1.25 to 2.25% molybdenum, 3 to 4.0% titanium and 0.15 to 0.25% carbon.

It is to be noted here that certain problems arise when titanium is present at one of the alloying elements. Titanium has an exceedingly high rate of reaction with certain of the gases contained in the atmosphere at elevated temperatures, rendering it next to impossible to alloy more than about 2.5% by weight of titanium in an air melting procedure. Further, in view of the fact that relatively small amounts of oxides, hydrides and nitrides of titanium cause a substantial reduction in the mechanical properties of alloys of this type, it is preferred that a vacuum melting process equivalent to that described in my previously granted U. S. Patent 2,564,498—Nisbet, be employed. This patent was filed August 26, 1949, given Serial No. 112,558, issued August 14, 1951, and assigned to the assignee of the present application.

A number of heats within the above-stated composition limits were prepared, heat treated and tested. The tests made included hardness tests to investigate age-hardening and allied characteristics, stress-rupture tests at elevated temperatures, and conventional tensile and fatigue tests. Representative results of these tests have been selected for reproduction in order to illustrate certain of the characteristics of this alloy.

TABLE I

Vickers hardness, 30 kg. load

Solution treated at 2,100° F., oil quenched, initial hardness 192 to 194

Aged (hours)	1,400° F.	1,500° F.	1,600° F.	1,700° F.	1,800° F.
1	271	285	240	189	193
2	280	282	236	201	196
4	302	289	229	204	195
8	308	275	250	196	203
16	329	281	249	167	192
32	324	281	238	192	201
64	321	276	248	200	193
100	321	290	248	220	191

From the data set forth in Table I, it is apparent that while the alloy exhibits some age-hardening, it is essentially quite stable at elevated temperatures.

TABLE II

Tensile properties

[Solution treated at 2,150° F., aged at 1,350° F.]

Heat Number	Temp., ° F.	Prop. Lim., p. s. i.	Ultimate T. S., p. s. i.	Ductility, Percent Elong.
279	Room	95,500	176,000	33
	1,200	96,500	140,000	18
	1,500	78,000	85,000	5
	1,600	61,000	63,000	29
	1,700	31,000	31,000	51
	1,800	13,500	14,000	110
299	Room	89,000	148,000	17
	1,200	86,000	114,000	13
	1,500	70,000	77,000	4
	1,600	61,000	62,000	13
	1,700	32,000	32,000	28
	1,800	13,500	14,000	95

Upon inspection of the data disclosed in Table II, it will be noted that the ultimate tensile strength of the alloy is about 80,000 p. s. i. with an elongation of about 5% when tested at 1500° F., for the heat treatment indicated.

TABLE III

Stress-rupture properties

[Solution treated at 2,150 °F., aged at 1,350 °F.]

Heat Number	Temp., °F	Stress, p. s. i.	Life, Hours	Ductility, Percent Elong. in 1"
165	1,500	25,000	136	26
166	1,500	30,000	70	20
		25,000	190	8
279	1,500	35,000	56	----
		30,000	132	17
		25,000	232	19
		20,000	524	7
299	1,500	35,000	60	9
			63	16
		30,000	107	12
			139	11
		25,000	232	15
			315	6
		20,000	552	7
			577	6

[Solution treated at 2,100 °F., aged at 1,400 °F.]

165	1,500	50,000	3	28
		40,000	12	25
		30,000	62	25
		20,000	547	32
	1,350	60,000	141	16
		50,000	497	----
166	1,500	50,000	9	43
		40,000	16	44
		30,000	113	36
		20,000	1,717	15
	1,650	20,000	4	94
		15,000	21	82
		10,000	200	62

Upon comparison of the stress-rupture properties set forth in Table III, it will be noted that apparently the heat treatment schedule of a solution treatment at 2100° F. and aging at 1400° F. produces somewhat superior results over the schedule of solution treatment at 2150° F. and aging at 1350° F. However, in view of all the data, the calculated stress-rupture strength of this alloy is not less than 18,500 p. s. i. for 1000 hours at 1500° F.

TABLE IV

Fatigue properties

[Solution treated at 2,150° F., aged at 1,350° F.]

Heat Number	Temp. °F	Stress p. s. i.	Cycles to Failure × 10^6
279	1,500	52,500	0.082
		47,500	0.110
		45,000	0.869
		42,500	15.65
299	1,500	45,000	0.222
		42,500	10.9
		40,000	0.444
		37,500	[1] 100

[1] Test terminated, specimen unbroken.

From the data of Table IV, it is apparent that this alloy has a fatigue strength of at least 38,000 p. s. i. at 1500° F. for 10^8 cycles.

It should be further noted that these alloys are of austenitic constituency and have excellent corrosion resistance at elevated temperatures.

In the evaluation of an alloy to be used at high temperatures under high stress, the most significant mechanical properties are indicated by stress-rupture and fatigue tests at high temperatures. A second and equally important consideration is the composition of the alloy, particularly with regard to the availability of the various elements of which it is composed. In view of these considerations, a table showing the compositions, stress-rupture strengths for 1000 hours at 1500° F. and the fatigue strengths at 10^8 cycles for several known alloys which are or have been commercially available having comparable mechanical properties will be of assistance for evaluating the alloy of my invention.

TABLE V

Alloy No.	Composition, Wt. Percent											Stress-Rupture	Fatigue Strength
	C	Cr	Ni	Co	Mo	W	Fe	Nb	Ti	Al	Other		
1	.40	20	20	43.7	4	4	2.8	3.75	----	----	----	17,500	35,500
2	.07	19.5	24.5	36.5	----	12	1.6	1.5	2.15	.75	----	18,800	45,000
3	.19	19.2	15.5	50	----	12	1.3	----	----	----	[1]	17,000	35,500
4	.07	18.5	24.5	40.5	----	12	1.6	1.2	----	----	.22B	17,500	[2] 60,000
5	.07	18.5	24.5	37.5	----	12	1.6	1.2	----	2.75	.22B	16,800	[2] 50,000
6	.10	19.5	10	51.3	----	14.5	2.5	----	----	----	.04B	16,200	[2] 55,000
7	.05	15	72.5	----	----	----	7	1	2.5	.7	.05Cu	16,500	38,500
8	.08	19.5	55.5	19.5	----	----	.5	----	2.5	1.2	----	17,700	38,000
9	.05	18	37	20	3	----	18	----	2.8	.2	----	19,400	[1] 49,500
10	.10	19	53.5	10	10	----	2	----	2.5	.75	----	18,700	45,000

[1] Tantalum and/or niobium.
[2] Fatigue strengths at 10^8 cycles at 1200° F.

While it is not contended that the above alloys are the only known high temperature wrought alloys which are or have been commercially available, these alloys have been selected from those so known as having the best mechanical properties and the closest chemical constituency to my alloy.

It will first be noted that the stress-rupture strengths of these alloys range from 16,200 p. s. i. to 19,400 p. s. i. for 1000 hours at 1500° F. My alloy has a stress-rupture strength under the same conditions of at least 18,500 p. s. i. On this basis alone, only alloys Nos. 2, 9 and 10 have a higher stress-rupture strength.

It will next be noted that the fatigue strengths for these alloys are given in pounds per square inch at 10^8 cycles at 1500° F., except for alloys Nos. 4, 5, 6 and 9, which are only known at 10^8 cycles at 1200° F. However, based on known behavior of other similar alloys, it may be fairly stated that a fatigue strength at 10^8 cycles at 1200° F. of more than 60,000 p. s. i. is necessary for alloys of this type to have a fatigue strength of approximately 38,000 p. s. i. at 10^8 at 1500° F. Making this assumption, it is then seen that only alloys Nos. 2, 7 and 10 have better fatigue strengths at 10^8 cycles and 1500° F. than my alloy.

It will then be noted that alloy No. 2 which has only a slightly higher stress-rupture strength and a somewhat higher fatigue strength than my alloy, contains almost twice as much cobalt and tungsten as my alloy, and further, 1.5% niobium, which my alloy lacks altogether. All of these elements are classified as "strategic" and are, relatively speaking, quite expensive.

In considering alloy No. 7 from the same basis of comparison, it is first to be noted that this alloy has a considerably lower stress-rupture strength, and, for all practical purposes, the same fatigue strength. This alloy, however, contains about two and one-half times as much nickel, an element which is becoming more and more difficult to obtain, as my alloy and further contains 1% niobium.

Alloy No. 9 has the highest stress-rupture properties of all these alloys and perhaps the lowest fatigue strength. It contains from 7 to 11% more nickel and about 1 to 1.5% more molybdenum than my alloy, but its low fatigue strength renders it quite inferior to my alloy for extended high temperature uses.

Alloy No. 10 has a stress-rupture strength about equal to my alloy, and a better fatigue strength, but it contains about twice as much nickel and about five times as much molybdenum.

From the foregoing, it is apparent that this invention provides a wrought alloy having mechanical properties at elevated temperatures which are better than or comparable to the best commercially available wrought alloys and which is further distinguished by the utilization of much lower amounts of critical or "strategic" metals.

It should be further noted that this alloy contains a much higher percentage of alloyed titanium than any known wrought high temperature alloy, and further, it should be noted that titanium is not a critical or "strategic" metal.

It is to be further noted, particularly with respect to the titanium content and the preferred vacuum melting technique employed, that this alloy has very low amounts of inclusions such as metallic oxides, hydrides and nitrides, all of which contributes to its high physico-chemical properties. These impurities exist in alloys of this type which have been vacuum melted in percentages of the order of 0.002% oxygen, 0.0001% hydrogen and 0.0005% nitrogen. This is important because of the extreme reactivity of titanium at elevated temperatures and the extremely debilitating effect upon an alloy of appreciable percentages of titanium oxides, hydrides and nitrides. It is for these reasons that no air-melted alloy of this type containing more than about 2.5% by weight titanium is known to have a stress-rupture strength at 1500° F. over about 14,000 to 16,000 p. s. i.

It is to be understood that small amounts of elements other than those specifically disclosed will inevitably be present in this or any other commercially produced alloy. However, these elements are present only as impurities and, as such, do not materially alter the composition of the alloy as will later be claimed, nor is it intended that such unspecified impurities will lend any color of patentability to the composition.

In view of the foregoing, it is my intention that my invention shall not be limited in any sense except as defined by the following claims.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A high temperature, high strength wrought alloy consisting essentially of, by weight, 18 to 22% cobalt, 26 to 30% nickel, 18 to 22% chromium, 6 to 7.5% tungsten, 1.25 to 2.25% molybdenum, 3 to 4% titanium, 0.15 to 0.25% carbon, and the balance being substantially all iron with the amounts of the other constituents being so selected that the iron content lies within the range 18 to 22%.

2. A high temperature, high strength wrought alloy consisting essentially of, by weight, 18 to 22% cobalt, 26 to 30% nickel, 18 to 22% chromium, 6 to 7.5% tungsten, 1.25 to 2.25% molybdenum, 3 to 4% titanium, 0.15 to 0.25% carbon, the balance being substantially all iron with the amounts of the other constituents being so selected that the iron content lies within the range 18 to 22%, and said alloy containing less than 0.006%, by weight, of free and combined oxygen, hydrogen, and nitrogen.

3. A high temperature, high strength wrought alloy consisting essentially of, by weight, about 18% cobalt, 29% nickel, 20.5% chromium, 7.4% tungsten, 2% molybdenum, 3.5% titanium, 0.20% carbon, and the balance being substantially all iron.

4. A high temperature, high strength wrought alloy consisting essentially of, by weight, about 18 cobalt, 29% nickel, 20.5% chromium, 7.4% tungsten, 2% molybdenum, 3.5% titanium, 0.20% carbon, the balance being substantially all iron, and said alloy containing less than 0.006%, by weight, free and combined oxygen, hydrogen, and nitrogen.

5. A wrought article having a stress-rupture life of at least 1000 hours at 1500° F. under a load of 18,500 p. s. i. and a fatigue strength at 1500° F. of at least 38,000 p. s. i. for 10^8 cycles, said article being composed of an alloy consisting essentially of, by weight, 18 to 22% cobalt, 26 to 30% nickel, 18 to 22% chromium, 6 to 7.5% tungsten, 1.25 to 2.25% molybdenum, 3 to 4% titanium, 0.15 to 0.25% carbon, the balance being substantially all iron with the amounts of the other constituents being so selected that the iron content lies within the range 18 to 22%, and said article containing less than 0.006%, by weight, free and combined oxygen, hydrogen, and nitrogen.

6. A wrought article having a stress-rupture life of at least 1000 hours at 1500° F. under a load of 18,500 p. s. i. and a fatigue strength at 1500° F. of at least 38,000 p. s. i. for 10^8 cycles, said article being composed of an alloy consisting essentially of, by weight, about 18% cobalt, 29% nickel, 20.5% chromium, 7.4% tungsten, 2% molybdenum, 3.5% titanium, 0.20% carbon, the balance being substantially all iron, and said article containing less than 0.006%, by weight, free and combined oxygen, hydrogen, and nitrogen.

References Cited in the file of this patent

UNITED STATES PATENTS

2,246,078	Rohn	June 17, 1941
2,397,034	Mohling	Mar. 19, 1946
2,475,642	Scott	July 12, 1949
2,513,469	Franks et al.	July 4, 1950