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W-8000 München 22 (DE)(54) **Super alloy with low thermal expansion.**

(57) The invention provides a low thermal expansion alloy which has an excellent high-temperature strength, a low coefficient of thermal expansion and a high notch rupture strength so that the alloy will be the most suitable as a material for components of a gas turbine or as a material connected with a low thermal expansion material.

The alloy consists essentially of, by weight, 0.2 % or less carbon, 1.0 % or less silicon, 1.0 % or less manganese, 0.5 to 2.95 % chromium, 0.25 to 1.0 % aluminum, 0.5 to 2.5 % titanium, one or both of niobium and tantalum in the range of $3.0 \% \leq \text{Nb} + [\text{Ta}/2] \leq 6.0 \%$, 0.02 % or less boron, 24 to 29.8 % nickel, 20 to 28 % cobalt, and the balance of iron.

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BACKGROUND OF THE INVENTION

The present invention relates to a super alloy which is used as a material for various components of a gas turbine or as a material connected with ceramics or cemented carbides and which must have an excellent high-temperature strength and a low coefficient of thermal expansion.

As an alloy for use which requires a low coefficient of thermal expansion, there have been conventionally known Invar alloy of Fe-36%Ni system, 42 Ni alloy of Fe-42%Ni system, Koval alloy of Fe-29%Ni-17%Co alloy system, and so forth. Although these alloys have a low thermal expansion coefficient, their strength at normal temperature and high temperature is low, so that they can not be used for parts which require high strength.

On the other hand, as an alloy whose thermal expansion coefficient is not so low as the coefficient of the above-mentioned alloys but smaller than that of usual austenitic alloys and which is increased in high-temperature strength by adding precipitation strengthener elements such as aluminum, titanium, niobium and so forth, there has been known Incoloy 903 alloy disclosed in JP-B1-41-2767. As a series of results of improvement of Incoloy 903 alloy, there have been known alloys disclosed in JP-A-50-30729, JP-A-50-30730, US-A-4200459, JP-A-59-56563, JP-A-60-128243, JP-A-53-6225, JP-A-50-30728, JP-B-63-43457, US-A- 4006011, PCT WO-A-92/03584 and so on.

Recently, in accordance with an increase of temperature of gas turbine components during operation, there has been an increasing demand for a material which has a high strength at a temperature range from normal to high and can maintain clearances between various members or parts such that the clearances have predetermined amounts from normal to high temperature, and also an increasing demand for improving the connecting property of connecting a low thermal expansion material such as ceramics and cemented carbides with a metallic material.

One example of such application is a turbo-collar for connecting a shaft and a blade member (usually made of ceramics) of a turbine rotor in an automobile. Other application examples are gas turbine components such as a compressor casing, an exhaust casing, a sealing member and so forth, a sleeve for aluminum die casting composed of an inner cylinder of ceramics and an outer cylinder of a low-thermal-expansion super alloy, and a cutter of cemented carbide with a low-thermal-expansion super alloy as a buffer material between cemented carbide and a base metal.

Conventionally, in response to the demands mentioned above, Incoloy 903 disclosed in JP-B1-41-2767 has been employed in practice. However, Incoloy 903 involves a drawback that it has a remarkably high notch sensitivity when it is used at about 500 ° C.

Actually, products of this kind of low-thermal-expansion super alloy include some stress concentration portions in many cases. If notch strength of such portions are lower than smooth portion strength, a rupture will be caused much earlier than the designed durability. Since such a drop in the notch strength of this kind of alloy is the most remarkable at about 500 ° C, practical application conditions of a material whose notch portion is ruptured earlier than the portion in a smooth and notch creep-rupture test at 500 ° C are extremely limited. Consequently, it is an important factor that the notch strength exceeds the smooth portion strength in the smooth and notch creep-rupture test at 500 ° C.

As a series of results of improvement in this respect, there have been suggested the above-mentioned alloys disclosed in JP-A-50-30729, JP-A-50-30730, US-A-4200459, JP-A-59-56563, JP-A-60-128243, JP-A-53-6225, JP-A-50-30728, JP-B-63-43457, US-A- 4006011 and so on, and of these improved alloys, Incoloy 909 is an alloy which has been selected for practical use. Indeed, Incoloy 909 has a notch rupture strength superior to that of Incoloy 903. However, it involves a problem that the metal structure is unstable when it is heated at a high temperature of 700 to 800 ° C, and a problem that its hardness is insufficient because the degree of age-hardening is inadequate when it is heated at a high temperature for a short time in a treatment such as soldering Incoloy 909 with ceramics or cemented carbides.

On the other hand, addition of chromium has been also investigated as a method of improving the notch sensitivity of Incoloy 903. However, in a range of the matrix composition of Fe-Co-Ni which has been conventionally studied, addition of chromium only results in an increase of the thermal expansion coefficient. Therefore, chromium of an amount enough to improve the notch sensitivity and oxidation resistance can not be added. Thus, addition of chromium is not practical.

The alloy disclosed in PCT WO-A-92/03584 contains 3 to 10% chromium. Consequently, it involves a problem that it is difficult to stably obtain a low thermal expansion property.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, there is provided a novel alloy having a low coefficient of thermal expansion.

According to another aspect of the invention, there is provided a novel low-thermal-expansion super alloy which has the same level of low thermal expansion property as the conventionally used low-thermal-expansion super alloys such as Incoloy 903 and Incoloy 909 and which enables compatibility of a high age-hardening property and a high notch rupture strength which could not be achieved by the known alloys.

In order to solve the above-described problems, the inventors of the present application performed experiments with alloys of Fe-Co-Ni system. As a result, the inventors found the optimum range of addition of chromium which contributes to improvement of age-hardening property and improvement of notch sensitivity, the ratios of iron, cobalt and nickel which provide a coefficient of thermal expansion as low as the thermal expansion coefficients of the conventional alloys even if chromium is thus added and which cause generation of a proper amount of precipitates of the Laves phase to make crystal grains finer and to improve the notch strength, and appropriate ranges of additions of titanium, niobium and aluminum to cause generation of precipitates of the gamma prime phase which are stable and have a high age-hardening property. In consequence, the inventors invented alloys including both a high-temperature strength and a low coefficient of thermal expansion, which had not been obtained from the conventional alloys.

More specifically, the invention provides a super alloy with low thermal expansion consisting essentially of, by weight, 0.2% or less carbon, 1.0% or less silicon, 1.0% or less manganese, 0.5 to 2.95% chromium, 0.25 to 1.0% aluminum, 0.5 to 2.5% titanium, one or both of niobium and tantalum in the range of $3.0\% \leq \text{Nb} + [\text{Ta}/2] \leq 6.0\%$, 0.02% or less boron, 24 to 29.8% nickel, 20 to 28% cobalt, and the balance of iron except for impurities, preferably, a low-thermal-expansion super alloy consisting essentially of, by weight, 0.1% or less carbon, 1.0% or less silicon, 1.0% or less manganese, 0.5 to 2.95% chromium, 0.25 to 1.0% aluminum, 0.5 to 2.5% titanium, 3.0 to 6.0% one or both of niobium and tantalum to satisfy the relation $\text{Nb} + [\text{Ta}/2]$, 0.01% or less boron, 27 to 29.8% nickel, 20 to 25% cobalt, and the balance of iron except for impurities.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an optical microscopic photograph of a micro-structure of an invention alloy No. 4 after thermal treatment;

Fig. 2 is an optical microscopic photograph of a micro-structure of a conventional alloy No. 21 after thermal treatment; and

Fig. 3 is an optical microscopic photograph of a micro-structure of a conventional alloy No. 22 after thermal treatment.

DETAILED DESCRIPTION OF THE INVENTION

Reasons for selecting restricted amount of each component of the invention alloy will be hereinafter described.

Carbon combines with titanium and niobium to produce carbides as to prevent coarsening of crystal grains and to contribute to improvement of the alloy strength. Excessive addition of carbon over 0.2% results in production of too much carbides of titanium and niobium so that amounts of titanium and niobium which may actually act as precipitation strengthener elements decrease and the coefficient of thermal expansion of the alloy becomes high. Therefore, the carbon content is limited to 0.2% or less. Preferably, it should be not more than 0.1%.

Silicon is an essential component element because it is effective as a deoxidizer and also because it promotes precipitation of the Laves phase which serves to make crystal grains finer and to improve the grain boundary configuration. However, if the silicon content exceeds 1%, hot workability and high-temperature strength will be deteriorated. Consequently, the silicon content is limited to 1.0% or less.

The alloy contains manganese as a deoxidizer. However, excessive addition of manganese is not favorable since it increases the thermal expansion coefficient of the alloy. Therefore, the manganese content is limited to 1.0% or less.

Chromium fulfills an important function in the invention in relation to improvement of age-hardening property and notch sensitivity. More specifically, chromium dissolves in the alloy matrix so as to promote precipitation of the gamma prime phase which is a precipitation strengthener phase. Thus, sufficient strength can be obtained even in the case of short-time aging, and it is also possible to increase resistance

against oxidation of the crystal grain boundary which is thought to be one factor to enhance the notch sensitivity. Consequently, the chromium content must be, at the minimum, 0.5% or more. However, if addition of chromium exceeds 2.95%, it will be difficult to stably obtain a low thermal expansion property no matter how ratios of iron, cobalt and nickel which constitute the alloy matrix are controlled. Therefore, the chromium content is limited to 0.5 to 2.95%.

In aging treatment, aluminum produces fine precipitates of the gamma prime phase which has a composition of $(\text{Ni}, \text{Co})_3(\text{Al}, \text{Ti}, \text{Nb})$ and a diameter of about several 10 nm, thereby remarkably improving the high-temperature tensile strength. When a concentration of aluminum in the gamma prime phase is decreased, high temperature of about 700 to 800 °C makes the gamma prime phase unstable, and the hexagonal crystal of η -phase and the rhombic crystal of δ -phase precipitate, so that the strength at normal temperature and high temperature will be deteriorated. Therefore, in order to produce stable precipitates of the gamma prime phase, the aluminum content must be, at the minimum, 0.25% or more. However, if addition of aluminum exceeds 1%, a large amount of precipitates of the gamma prime phase are generated, thus deteriorating the hot workability. Consequently, the aluminum content is limited to 0.25 to 1.0%.

Titanium and niobium combine with carbon to produce carbides, as described above, and the rest of titanium and niobium as well as aluminum combine with nickel, cobalt and so forth, as will be described below, as to form the gamma prime phase, thereby strengthening the alloy.

As a result of aging treatment, titanium generates precipitates of the gamma prime phase with nickel, cobalt, aluminum and niobium so as to improve high-temperature tensile strength remarkably. The amount of titanium required for this purpose is 0.5% at the minimum. However, excessive addition of titanium over 2.5% makes the gamma prime phase unstable, and also results in an increase in the thermal expansion coefficient and deterioration of hot workability. Therefore, the titanium content is limited to 0.5 to 2.5%.

In substantially the same manner as titanium, niobium generates precipitates of the gamma prime phase with nickel, cobalt and aluminum as a result of aging treatment, so as to improve high temperature strength significantly. Further, part of niobium generates precipitates of the Laves phase having a diameter of about several micron at grain boundaries and inner grains, thereby making the crystal grains finer, increasing the grain boundary strength, and remarkably improving the high-temperature tensile strength and the notch creep-rupture strength at about 500 °C. The amount of niobium required for this purpose is 3.0% or more. However, excessive addition of niobium over 6.0% results in an increase in the thermal expansion coefficient and deterioration of hot workability. Consequently, the niobium content is limited to 3.0 to 6.0%. Moreover, tantalum is a homologous element of niobium and has an atomic weight two times as large as niobium, so that a part of niobium can be substituted in a range of $3.0\% \leq \text{Nb} + [\text{Ta}/2] \leq 6.0\%$.

Boron segregates at crystal grain boundaries and enhances the grain boundary strength so that it contributes to improvement of hot workability and notch creep-rupture strength at about 500 °C. Therefore, boron is effective even if the amount is very small. On the other hand, excessive addition of boron over 0.02% results in production of borides which causes the lower melting point of the alloy to drop, thus deteriorating the hot workability. Consequently, the boron content is limited to 0.02% or less. Preferably, the boron content should be 0.01% or less.

Nickel forms the alloy matrix together with cobalt and iron, and the amounts of iron, cobalt and nickel affect the thermal expansion coefficient of the alloy and a precipitation state of intermetallic compounds.

A low coefficient of thermal expansion at up to 400 °C-500 °C, which the invention super alloy is directed to have, may be obtained by causing the alloy to have Curie point of from 300 °C to 500 °C. Curie point is relative to total amount of nickel and cobalt in the alloy. The more the total amount of nickel and cobalt is, the higher Curie point of the alloy becomes. However, a coefficient of thermal expansion of the alloy becomes higher in proportion to the total amount of nickel and cobalt. Thus, preferably, the total amount of nickel and cobalt in the alloy is limited up to 55%. If the total amount of nickel and cobalt in the alloy is too small, Curie point becomes lower and the coefficient of thermal expansion at 400 °C-500 °C increases. Accordingly, it is preferred that the total amount of nickel and cobalt in the alloy is at least about 48%.

On the other hand, the more iron and cobalt in the alloy, the more easy Laves phase contributing to strengthening of grain boundaries precipitates. However, increasing of iron in the alloy, which means that the total amount of nickel and cobalt becomes smaller, is limited in relation to the requirement to the coefficient of thermal expansion mentioned above. Thus, amount of precipitation of Laves phase in the alloy is preferably controlled by controlling of the ratio of $\text{Ni}/[\text{Ni} + \text{Co}]$. The notch strength level of the alloy aimed in the invention is readily attained by causing the ratio of $\text{Ni}/[\text{Ni} + \text{Co}]$ to be not more than 0.6 and precipitating Laves phase.

The invention alloy contains a large amount of precipitation strengthener elements such as titanium, niobium and aluminum in order to obtain the highest level of high-temperature strength as compared with

the conventional alloys. With the ratio of $\text{Ni}/[\text{Ni} + \text{Co}]$ which can be found in none of the conventional alloys, the invention alloy enables compatibility of a superior high-temperature tensile strength and a low thermal expansion coefficient. Further, with the amounts and ratios of iron, cobalt and nickel (namely, the ratio of $\text{Ni}/[\text{Ni} + \text{Co}]$) in the invention alloy, a much larger amount of fine spherical precipitates of the Laves phases are produced than that of the conventional alloys such as Incolloy 903 and 909, so as to serve to strengthen grain boundaries and to take effects in increasing the notch creep-rupture strength at about 500°C .

The amount of nickel required for this purpose is 24% or more. If the nickel content is less than 24%, the austenitic phase becomes unstable, and also, precipitation of the gamma prime phase becomes insufficient. In consequence, aging responsiveness is degraded, and the high-temperature strength is deteriorated. On the other hand, since addition of nickel exceeding 29.8% results in an increase of the thermal expansion coefficient and a decrease in the amount of precipitation of the Laves phase, it is difficult to make crystal grains finer and to strengthen grain boundaries so that the object of the invention can not be achieved. Therefore, it is important that the nickel content is 24 to 29.8%.

In substantially the same manner as nickel, as stated above, cobalt forms the alloy matrix together with iron and serves to decrease the thermal expansion coefficient and to promote precipitation of the Laves phase. The alloy has to contain 20% or more of cobalt. On the other hand, since the amount of cobalt exceeding 28% results in an increase of the thermal expansion coefficient and a decrease in the high-temperature strength owing to excessive precipitation of the Laves phase, the cobalt content is limited in a range of 20 to 28%. Preferably, the cobalt content should be in a range of 20 to 25%.

Example:

Experiment 1

Table 1 shows chemical compositions of the invention alloys, comparative alloys and conventional alloys. Table 1 also includes the total amount of nickel and cobalt, and the ratio of $\text{Ni}/[\text{Ni} + \text{Co}]$. The invention alloys and the conventional alloys were melted in a vacuum induction furnace and molded to ingots of 10 kg. Ingots were maintained at 1150°C for 20 hours for soaking treatment. After that, they were forged at a heating temperature of 1100°C and formed into samples of 30 mm square. Next, all samples except for a conventional alloy No. 21 were solution-treated by maintaining the alloys at 982°C for one hour followed by air cooling. The conventional alloy No. 21 was solution-treated by maintaining at 930°C for one hour followed by air cooling.

TABLE 1

KIND OF ALLOY	NO.	CHEMICAL COMPOSITION (wt%)											Ni+Co	Ni Ni+Co
		C	Si	Mn	Ni	Cr	Co	Al	Ti	Nb	Ta	B	Fe	
INVENTION ALLOY	1	0.050	0.15	0.21	28.8	2.33	22.3	0.33	1.55	4.21	-	0.003	Bal	51.1 0.564
	2	0.032	0.74	0.40	28.8	1.78	24.0	0.86	0.77	4.12	-	0.008	"	52.8 0.545
	3	0.011	0.56	0.05	29.0	2.55	23.3	0.41	2.29	3.34	-	0.002	"	52.3 0.554
	4	0.035	0.31	0.10	29.5	2.05	22.5	0.54	1.30	4.07	-	0.004	"	52.0 0.567
	5	0.080	0.40	0.51	29.6	0.77	20.8	0.55	1.33	5.22	-	0.007	"	50.4 0.587
	6	0.031	0.40	0.15	29.3	2.03	22.3	0.51	1.20	-	7.85	0.004	"	51.6 0.568
	7	0.025	0.35	0.22	29.5	1.85	22.6	0.48	1.35	2.11	4.05	0.005	"	52.1 0.566
	8	0.027	0.32	0.11	29.3	1.60	20.5	0.57	1.25	4.01	-	0.005	"	49.8 0.588
	9	0.036	0.31	0.10	31.4	1.54	20.2	0.55	1.29	4.07	-	0.004	Bal	51.6 0.609
	10	0.031	0.01	0.01	37.8	1.83	15.1	0.47	1.25	4.11	-	-	"	52.9 0.715
	11	0.038	0.42	0.11	29.0	-	23.1	0.53	1.33	4.15	-	0.004	"	52.1 0.557
	12	0.031	0.21	0.21	29.4	4.64	21.8	0.60	1.35	4.09	-	0.005	"	51.2 0.574
	13	0.003	0.44	0.33	29.1	1.83	22.6	-	1.55	4.73	-	0.005	"	51.7 0.563
COMPARATIVE ALLOY														

TABLE 1 (cont'd)

CONVENTIONAL ALLOY	21	0.030	0.03	0.10	38.0	-	15.0	0.85	1.42	2.96	-	-	Bal	53.0	0.717
	22	0.040	0.46	0.01	38.0	-	13.2	0.03	1.52	4.71	-	0.004	"	51.2	0.742
INVENTION ALLOY	31	0.150	0.27	0.22	29.5	2.95	23.2	0.71	1.46	4.22	-	0.003	Bal	52.7	0.560
	32	0.030	0.28	0.09	29.4	2.04	22.4	0.41	0.99	3.68	-	0.004	"	51.8	0.568
	33	0.180	0.42	0.80	26.6	2.21	25.5	0.62	1.41	-	5.83	0.018	"	52.1	0.511
	34	0.170	0.35	0.44	29.0	2.24	22.4	0.60	1.31	3.11	1.73	0.010	"	51.4	0.564

The conventional alloy No. 21 was Incoloy 903, and a conventional alloy No. 22 was Incoloy 909. The solution treatment temperature of Incoloy 903 (No. 21) alone was 930°C and lower than that of the other alloys because a recrystallization temperature of the alloy was so low that crystal grains would easily grow.

Conditions of the aging treatment were similar to practical conditions of bonding treatment by soldering the sample alloys with ceramics or cemented carbides. The samples were maintained at 850°C for 30

minutes, cooled in a furnace down to 650 °C at a cooling speed of 100 °C/h, and cooled in air.

This thermal treatment is performed at a higher temperature in a shorter time as compared with the standard aging treatment of the conventional Incoloy 903 or Incoloy 909.

Of the alloys in Table 1, Figs. 1-3 show optical microscopic photographs of micro-structures of invention alloy No. 4 and the conventional alloys Nos. 21 and 22 after the thermal treatment, respectively. It can be understood from Fig. 1 that the invention alloy No. 4 has fine crystal grains, and that fine precipitates of the Laves phase are uniformly distributed at grain boundaries and inner grains. Referring to Fig. 2, on the other hand, in spite of the fact that the solution treatment temperature was lowered, crystal grains of the conventional alloy No. 21 (Incoloy 903) coarsen, and no precipitation of the Laves phase is observed at grain boundaries and inner grains such as in the invention alloy. Referring to Fig. 3, in relation to the conventional alloy No. 22 (Incoloy 909), acicular precipitates of δ -phase are observed in inner grains as well as a small amount of precipitates of the Laves phase as a result of high-temperature aging treatment. Due to the precipitation of δ -phase, sufficiently high tensile strength at normal temperature and high temperature can not be obtained.

Experiment 2

Table 2 shows tensile properties at normal-and temperature at 500 °C, smooth and notch creep-rupture properties at 500 °C and average thermal expansion coefficients at a temperature range from 30 °C to 400 °C of the invention alloys, comparative alloys and conventional alloys. Tensile test at both normal temperature and 500 °C were performed according to a test method specified in the ASTM method with small-scale tensile test pieces of A370 having a parallel part diameter of 6.35 mm and a gauge length of 25.4 mm. Also, smooth and notch creep-rupture tests were performed according to a test method specified in the ASTM method, and No. 8 test pieces of A453 whose smooth and notch portions both have a diameter of 4.52 mm and whose smooth portion has a gauge length of 18.08 mm. The test temperature was 500 °C, and the tests were effected with an initial stress of 500 N/mm² (50 kgf/mm²) for Nos. 21 and 22 and with an initial stress of 800 N/mm² (80 kgf/mm²) for any of the other alloys. A stress of 50 N/mm² (5 kgf/mm²) was added every 8 to 16 hours to those alloys whose rupture time had exceeded 200 hours so as to rupture them intentionally.

TABLE 2

KIND OF ALLOY	NO.	TENSILE PROPERTY AT NORMAL-TEMPERATURE		TENSILE PROPERTY AT 500°C	
		TENSILE STRENGTH (kgf/mm ²)*	ELONGATION (%)	TENSILE STRENGTH (kgf/mm ²)*	ELONGATION (%)
INVENTION ALLOY	1	117.8	20.5	103.7	21.2
	2	125.2	20.8	110.7	18.8
	3	121.1	19.9	106.0	22.1
	4	120.9	17.4	105.1	18.2
	5	120.0	21.1	107.7	18.9
	6	122.1	18.9	108.3	18.0
	7	122.4	19.5	107.0	19.4
	8	120.3	20.4	106.5	22.3
COMPARATIVE ALLOY	9	120.6	19.2	107.5	19.5
	10	119.4	23.6	109.9	19.7
	11	113.3	22.5	98.8	20.3
	12	125.8	21.3	111.4	21.9
	13	113.1	22.0	96.6	22.8
CONVENTIONAL ALLOY	21	118.9	24.2	102.0	19.9
	22	111.9	23.2	94.0	27.4
INVENTION ALLOY	31	129.1	17.1	113.3	16.3
	32	117.1	22.5	104.4	20.3
	33	117.2	16.5	103.5	16.6
	34	117.7	18.5	106.2	17.4

TABLE 2 (cont'd)

SMOOTH AND NOTCH CREEP-RUPTURE PROPERTY AT 500°C				THERMAL EXPANSION COEFFICIENT
INITIAL STRESS (kgf/mm ²)*	RUPTURE STRESS (kgf/mm ²)*	DURA- BILITY (hr)	ELONGA- TION (%)	α_{30-400} ($\times 10^{-6} \text{ } ^\circ\text{C}/$)
80	105	248.1	20.3	7.44
80	110	288.3	8.8	8.21
80	110	267.7	13.3	7.55
80	110	263.5	13.9	7.92
80	110	270.0	18.8	7.26
80	110	285.3	14.4	8.31
80	110	277.7	17.4	8.14
80	110	277.5	13.4	7.41
80	100	241.4	N	7.72
80	80	190.0	N	8.85
80	95	230.8	N	7.15
80	110	279.9	21.7	9.16
80	100	244.1	18.5	7.68
50	50	103.3	N	8.28
50	100	349.9	19.7	8.34
80	115	344.1	10.8	8.30
80	105	244.4	20.8	7.31
80	105	248.3	10.1	8.32
80	105	253.3	16.1	7.73

* 1 kgf/mm² = 10 N/mm²

Table 2 shows initial stresses and stresses at the eventual rupture time (in the column of rupture stress), total test time until rupture (in the column of durability), and values of elongation when a rupture occurs at a smooth zone and symbols N when a rupture occurs at a notch portion in the column of elongation. As thermal expansion coefficients, average thermal expansion coefficients in a temperature range from 30°C to 400°C were obtained by using test pieces having a diameter of 5 mm and a length of 19.5 mm.

It can be understood from Tables 1 and 2 that any of the invention alloys Nos. 1 to 8 and Nos. 31 to 34 has excellent tensile strength at normal temperature and 500°C, and causes a rupture at a smooth zone in the smooth and notch creep-rupture test at 500°C, which leads to a conclusion that the notch strength is larger than the strength at smooth zone, and that its rupture stress is high. Moreover, concerning the average thermal expansion coefficient in a range from normal temperature to 400°C, any of the invention alloys exhibits a value of $8.5 \times 10^{-6}/^{\circ}\text{C}$ or less, from which it can be understood that the invention alloys have thermal expansion coefficients as low as those of the conventional alloys Nos. 21 and 22.

On the other hand, it is believed that comparative alloy No. 9 ruptured at a notch portion because precipitation of the Laves phase was insufficient in spite of the fact that it has substantially the same composition as the invention alloy No. 8 except for the nickel content of 30% or more which is slightly higher than that of the alloy No. 8.

A comparative alloy No. 10 has a matrix composition of high nickel and low cobalt in comparison with the invention alloys, and is disclosed in JP-A-53-6225. Although high level of tensile strength at normal and high temperatures can be obtained with this composition, the Ni/[Ni+Co] ratio is too high so that no precipitates of the Laves phase are generated, and that crystal grains coarsen to induce a rupture in a notch portion. Also, the thermal expansion coefficient is inferior to the coefficients of the invention alloys.

A comparative alloy No. 11 has a composition containing no chromium unlike the invention alloys. Therefore, as a result of high-temperature short-time aging, precipitates of the gamma prime phase are not generated adequately so that the strength is inferior to the strength of the invention alloys. Further, since the grain boundary oxidation resistance is low, a rupture is caused in a notch portion.

A comparative alloy No. 12 contains a larger amount of chromium than the invention alloys so that favorable normal-temperature and high-temperature tensile strengths can be obtained. However, the thermal expansion coefficient is too high.

A comparative alloy No. 13 contains no aluminum in comparison with the invention alloys. Since No. 13 alloy contains less precipitation of the gamma prime phase which improves high temperature strength of such alloy and the gamma prime phase contains no aluminum, No. 13 alloy is deteriorated in tensile strength at 500°C as shown in Table 2.

The conventional alloy No. 21 (Incoloy 903) can provide substantially the same level of tensile strength at normal-temperature and 500°C as the invention alloys. However, its notch strength at 500°C is extremely low. The reason why notch sensitivity of the conventional alloy No. 21 (Incoloy 903) is abnormally high is that the niobium content is slightly low, and that the ratio of Ni/[Ni+Co] is too high to obtain a metal structure having precipitation of the Laves phase, so that the grain boundary strength will be inadequate.

The conventional alloy No. 22 (Incoloy 909) contains less aluminum and more niobium than the conventional alloy No. 21 (Incoloy 903). Even if the ratio of Ni/[Ni+Co] of No. 22 alloy is approximately equal to that of No. 21 alloy, precipitates of the Laves phase are produced because of increased niobium, and the notch rupture strength is certainly improved. However, since it does not contain enough aluminum, stable precipitation of the gamma prime phase can not be caused when it is subjected to high-temperature aging, thus deteriorating the strength obviously as compared with the invention alloys.

When the alloys of the invention are used for components of a gas turbine, parts connected with ceramics, cemented carbides or the like, the high-temperature strength and the low thermal expansion property, which could not be obtained from the conventional alloys, may be obtained at once, and it is possible to apply the invention alloys to a structural material which requires high strength at a temperature range from normal to high temperature and maintenance of clearances between various members or parts such that the clearances have predetermined amounts at a temperature range from normal to high temperature. Moreover, when a low thermal expansion material such as ceramics and cemented carbides is connected with a structural material via an intermediate material of the invention alloy, high-strength highly reliable connecting may be effected.

Claims

1. A super alloy with low thermal expansion consisting essentially of, by weight, 0.2% or less carbon, 1.0% or less silicon, 1.0% or less manganese, 0.5 to 2.95% chromium, 0.25 to 1.0% aluminum, 0.5 to 2.5% titanium, one or both of niobium and tantalum in the range of $3.0\% \leq \text{Nb} + [\text{Ta}/2] \leq 6.0\%$, 0.02% or less boron, 24 to 29.8% nickel, 20 to 28% cobalt, and the balance of iron except for impurities.
2. A super alloy with low thermal expansion according to Claim 1, wherein said carbon content is 0.1% or less, said boron content is 0.01% or less, said nickel content is 27 to 29.8%, and said cobalt content is 20 to 25%.

3. A super alloy with low thermal expansion according to claim 1 or 2, wherein the ratio of Ni/[Ni + Co] by weight is not more than 0.6.
4. The use of a super alloy according to anyone of claims 1 to 3 as a material for components of a gas turbine.
5. The use of a super alloy according to anyone of claims 1 to 3 as a material connecting ceramics or cemented carbides with a metallic material.

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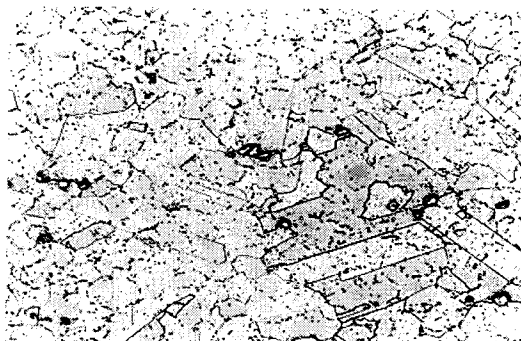
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FIG. 1

INVENTION
ALLOY

No. 4



50 μ m

FIG. 2

CONVENTIONAL
ALLOY

No. 21



50 μ m

FIG. 3

CONVENTIONAL
ALLOY

No. 22



50 μ m



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 11 5504

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	EP-A-0 104 738 (HUNTINGTON ALLOYS) *Claims 1-6* ---	1-3	C22C30/00 C22C38/10
A	EP-A-0 433 072 (INCO ALLOYS INTERNATIONAL) *Claims 1,2, 5-8, 13, 16* ---	1-3	
A	GB-A-997 767 (INTERNATIONAL NICKEL LIMITED) * the whole document * ---	1-3	
A	FR-A-2 357 652 (HENRY WIGGIN & CY. LTD.) *Claims 1-11; page 19, 1.1-7* -----	1-4	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			C22C
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 04 DECEMBER 1992	Examiner LIPPENS M.H.
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			