

(19)



Europäisches Patentamt

European Patent Office

Office européen des brevets



(11)

EP 1 035 225 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

13.09.2000 Bulletin 2000/37

(51) Int. Cl.⁷: **C22C 19/05**

(21) Application number: **00104667.1**

(22) Date of filing: **03.03.2000**

(84) Designated Contracting States:

**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE**

Designated Extension States:

AL LT LV MK RO SI

(30) Priority: **03.03.1999 JP 5605999**

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(54) **Ni-base superalloy**

(57) A low thermal expansion Ni-base superalloy contains, by weight % (hereinafter the same as long as not particularly defined), C: 0.15 % or less; Si: 1 % or less; Mn: 1 % or less; Cr: 5 to 20 %; at least one of Mo, W and Re of $Mo + \frac{1}{2}(W + Re)$ of 10 to 25 %; Al: 0.2 to 2 %; Ti: 0.5 to 4.5 %; Fe of 10 % or less; at least one of B: 0.02 % and Zr: 0.2 % or less; a remainder of Ni and inevitable impurities; wherein the atomic % of Al + Ti is 2.5 to 7.0.

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Description

[0001] The present invention relates to a low thermal expansion Ni superalloy.

[0002] In recent years, the bolt material for high temperature which is used for a pressure vessel member which is heated to the high temperature, such as a chamber of a steam turbine and gas turbine is made of 12 Cr ferritic steel (containing C: 0.12 %, Si: 0.04 %, Mn: 0.7 %, P: 0.1 %, Ni: 0.4 %, Cr: 10.5 %, Mo: 0.5 %, Cu: 0.03 %, V: 0.2 %, W: 1.7 %, Nb: 0.1 % and Fe : remaining percent) or austenitic heat-resistant alloy (Nimonic alloy 80A including Cr: 10.5 %, Mn: 0.4 %, Al: 1.4 %, Ti: 2.4 %, Si: 0.3 %, C: 0.06 %, Zr: 0.06 %, B: 0.003 %, Ni: remaining percent, and Refrataloy 26 including Cr: 18 %, Co: 20 %, Mo: 3 %, Ti: 2.6 %, Fe: 16 %, C: 0.05 %, Ni: remaining percent).

[0003] In recent years, in order to improve the thermal efficiency of a steam turbine, the steam temperature has been further raised so that the high temperature bolt has been used under more severe conditions. Where each of the materials described above is used for the high temperature bolt under such a severe condition, 12 Cr ferritic steel is low in cost and excellent in production. However, if the steam temperature becomes higher than at present, the material is low in the strength at the high temperature. On the other hand, austenitic heat-resistant alloy is more excellent in the corrosion-resistance and oxidation-resistance than the 12 Cr ferritic steel, and high in the high temperature strength. However, because it has a higher linear expansion coefficient than that of 12 Cr ferritic steel, it may produce leakage of steam due to insufficient tightening of the bolt, and generate thermal fatigue. Therefore, austenitic heat-resistance alloy is also problematic as a material used at higher temperatures.

[0004] JP-A-9-157779 discloses a low thermal expansion Ni-base super heat-resistant alloy with excellent corrosion-resistance and oxidation-resistance containing, by weight %, C of 0.2 % or less, Si of 1 % or less, Mn of 1 % or less, Cr of 10 to 24 %, one or more kinds of Mo and W of Mo + 1/2 W of 5 to 17 %, Al of 0.5 to 2 %, Ti of 1 to 3 %, Fe of 10 % or less, B of 0.02 or less and Zr of 0.2 % or less, and as necessary Co of 5 % or less and Nb of 1.0 % or less and remainder of Ni and inevitable impurities. JP-A-8-85838 also discloses a similar alloy.

[0005] A previously known example of alloys having a low linear expansion coefficient is Inconel 783 of an Invar alloy (containing Cr: 3.21 %, Mn: 0.08 %, Al: 5.4 %, Ti: 0.2 %, Si: 0.07 %, C: 0.03 %, B: 0.003 %, Fe: 24.5 %, Ni: 28.2 % and Co: 35.3 % Comparative Example No. 2) which has been developed as the material for a jet engine. This alloy has a low linear expansion coefficient in a ferromagnetic state with the Curie point adjusted in the balance of Fe-Ni-Co. However, this alloy does not have corrosion-resistance enough to be used for the steam turbine.

[0006] It is the object of the present invention to provide a low expansion Ni-base superalloy which overcomes the drawbacks of the prior art materials, in particular a low expansion Ni-base superalloy having a linear expansion coefficient approximately equal to 12 Cr ferritic steel, and high-temperature strength and corrosion/oxidation-resistance approximately equal to the above austenite heat-resistant alloy.

[0007] This object is solved by the low thermal expansion Ni-base superalloy according to independent claim 1. Further advantageous features, aspects and details of the invention are evident from the dependent claims and the description. The claims are to be understood as a first non-limiting approach to define the invention in general terms.

[0008] This invention relates to a low thermal expansion Ni superalloy having high strength and excellent corrosion-resistance and oxidation-resistance.

[0009] In order to solve the above problems, the inventors of the invention have eagerly investigated the low linear expansion Ni-base superalloy. As a result, the inventors found that as regards Mo, W and Re, when the value represented by Mo + 1/2 (W + Re) is 10 or more, the target thermal expansion coefficient can be obtained; in order to increase the thermal expansion coefficient in this case, Cr should be 20 % or less; the thermal expansion coefficient further lowers where the value of Mo + 1/2 (W + Re) exceeds 17 and Cr is lower than 10 %; and even if Cr is lower than that of a conventional Ni-base heat-resistant alloy, a problem of steam oxidation does not occur, and have accomplished the invention on the basis of these findings.

[0010] A low thermal expansion Ni-base superalloy of the present invention comprises, by weight % (hereinafter the same as long as not particularly defined), C: 0.15 % or less; Si: 1 % or less; Mn: 1 % or less; Cr: 5 to 20 %; at least one of Mo, W and Re of Mo + 1/2 (W + Re) of 10 to 25 %; Al: 0.2 to 2 %; Ti: 0.5 to 4.5 %; Fe of 10 % or less; at least one of B: 0.02 % and Zr: 0.2 % or less; a remainder of Ni and inevitable impurities; wherein the atomic % of Al + Ti is 2.5 to 7.0.

[0011] In the low thermal expansion Ni-base superalloy, it is preferable that the amount of Cr is from 5 to 10 (exclusive) %; wherein the amount of at least one of Mo, W and Re of Mo + 1/2 (W + Re) is from 17 (exclusive) to 25 %; the amount of Al is from 0.2 to 0.4 (exclusive) %; and/or the amount of Ti is from 3.5 (exclusive) to 4.5 %.

[0012] The low thermal expansion Ni-base superalloy may further comprises at least one of Nb and Ta in Nb + 1/2 Ta: 1.5 % or less; wherein the atomic % of Al + Ti + Nb + Ta is 2.5 to 7.0.

[0013] In the low thermal expansion Ni-base superalloy, a part of Ni may be replaced by Co of 5 % or less. In the low thermal expansion Ni-base superalloy, it is preferable that an average expansion coefficient at a temperature from room temperature to 700 °C is $14.0 \times 10^{-6}/^{\circ}\text{C}$ or less.

[0014] An explanation will be given of the reason why the composition of the components is defined as described above.

C : 0.15 % or less

[0015] Element C is contained to create carbide in combination with Ti, Nb, Cr and Mo, enhance the high-temperature strength and prevent the size of the crystal grain from increasing. The contents of C exceeding 0.15 % decreases the property of hot working so that it is 0.15 % or less and preferably 0.10 % or less.

Si : 1 % or less

[0016] Element Si is added as deoxidant and contained to increase the oxidation resistance. The contents of Si exceeding 1 % reduces ductility so that it is 1 % or less, preferably 0.5 % or less.

Mn : 1 % or less

[0017] Element Mn is added as deoxidant like Si. The contents of Mn exceeding 1 % deteriorates the high temperature oxidation characteristic and also promotes precipitation of η phase (Ni, Ti) spoiling the ductility so that it is 1 % or less, preferably 0.5 % or less.

Cr : 5 to 20 %

[0018] Cr is contained to improve the high temperature resistance and corrosion resistance through solid solution in the austenite phase. In order to maintain the sufficient high temperature oxidation resistance and corrosion resistance, although more contents of Cr is desired, it increases the thermal expansion coefficient so that it is desired to be less from the standpoint of view of the thermal expansion.

[0019] In order to obtain a target thermal expansion coefficient in the vicinity of 650 to 700 °C which is a using temperature intended by the invention, the contents of Cr of 5 to 20 % is desired. In order to obtain a lower thermal expansion coefficient, the contents of Cr is preferably 5 to 15 %, and further to lower the thermal expansion coefficient, the contents of Cr is preferably 5 to 10 (exclusive) %.

Mo + 1/2 (W + Re) : 10 to 25 %

[0020] Elements Mo, W and Re are contained in order to increase the high temperature strength through strengthening of solid solution in the austenite phase and reduce the thermal expansion coefficient. In order to obtain the thermal expansion coefficient intended by the invention, the total of one or more kinds of Mo + 1/2 (W + Re) is at least 10 % or more. The total of them exceeding 25 % reduces the property of hot working and precipitates the embrittling phase to reduce the ductility so that the contents of Mo + 1/2 (W + Re) is set at 10 to 25 %. In order to obtain a lower thermal expansion coefficient, the contents of Mo + 1/2 (W + Re) is preferably 17 (exclusive) to 25 %.

Ti : 0.5 to 4.5 %

[0021] Element Ti is contained to strengthen the γ' phase formed in combination with Ni, reduce the thermal expansion coefficient and promote the effect of aging precipitation in the γ' phase. In order to provide such an effect, the contents of 0.5 % or more must be contained. However, the contents of 4.5 % or more precipitates the η phase (Ni, Ti) of the embrittling phase to reduce ductility so that it is set at 0.5 to 4.5 %. In order to obtain the sufficient strength and low thermal expansion coefficient at the using temperature of 700 °C intended by the invention, the contents of Ti preferably exceeds 3.5 % and 4.5 % or less.

Al : 0.2 to 2.0 %

[0022] Element Al is the most important element to create the γ' phase in combination with Ni and strengthen by its precipitation. The contents of less than 0.2 % provides insufficient precipitation of the γ' phase. Where a large quantity of Ti, Nb and Ta makes the γ' phase unstable and precipitates η phase and phase to cause embrittlement. The contents of 2.0 % or more deteriorates the property of hot working and makes it impossible to forge a component. Therefore, the contents is set at 0.2 to 2.0 % and preferably 0.2 to 0.4 (exclusive) %.

Fe : 10 % or less

[0023] Element Fe is an impurity contained when inexpensive scrap or inexpensive mother alloy containing W, Mo, etc. is used in order to reduce the cost of the alloy. The element Fe decreases the high temperature strength and

increases the thermal expansion coefficient. Although the less content thereof is preferred, the content of 10 % or less slightly influences the high temperature strength so that it is set at 10 % or less. Preferably, it is 5 % or less, and more preferably, it is 2 % or less.

5 B : 0.02 % or less, Zr: 0.2 % or less

[0024] Elements B and Zr segregates in a crystal grain boundary to increase the creep strength. In addition, the element B can suppress the precipitation of η -phase in the alloy containing a larger quantity of Ti. These elements B and Zr are contained to provide such an effect. Excessive content of these elements deteriorates the property of hot working and excessive Zr spoils the creep characteristic. For these reasons, the content of B is set at 0.02 % and that of Zr is set at 0.2 % or less.

Co : 5 % or less

15 **[0025]** Element Co is contained to increase the high temperature strength in solid solution in the alloy. However, the effect is relatively low as compared with the other elements and expensive. For this reason, the content thereof is set at 5 % or less.

Nb + 1/2 Ta : 1.5 % or less

20 **[0026]** Elements Nb and Ta can form the γ' phase ($\text{Ni}_3(\text{Al}, \text{Nb}, \text{Ta})$) which is a precipitation strengthening phase of Ni-base superalloy and have the effects of strengthening the γ' phase and preventing the coarsening of γ' phase. These elements are contained to provide such an effect. Excessive content thereof precipitates the δ phase ($\text{Ni}_3(\text{Nb}, \text{Ta})$) to lower ductility. For this reason, the content of Nb + 1/2 Ta is set at 1.5 %. The desired range is 1.0 % or less.

25 Ni : remainder

[0027] Element Ni is a main element to create austenite which serves as matrix, and can increase heat-resistance and corrosion-resistance. In addition, Ni forms the γ' phase which is a precipitation strengthening phase.

30 Al + Ti : 2.5 to 7.0 % by atomic %, Al + Ti + Nb + Ta: 2.5 to 7.0 % by atomic %

[0028] Elements Al, Ti, Nb and Ta are constituents of the γ' phase. Therefore, where there is sufficient quantity of Ni, the volume fraction of the precipitated γ' phase is proportional to the total of the atomic percent of these elements. Further, the high temperature strength is proportional to the volume fraction of the γ' phase so that it increases with the total of these elements. Therefore, the content thereof of 2.5 % or more is required to acquire the sufficient strength. However, the contents thereof exceeding 7.0 % excessively increases the volume fraction of the γ' phase to deteriorate the property of hot working remarkably. For this reason, the content thereof is set at 2.5 to 7.0 % by atomic %, preferably 3.5 to 6.0 %.

40 Other elements

[0029] As regards elements Mg, Ca, P, S and Cu, the property of the low thermal expansion Ni-base superalloy according to the invention will not be deteriorated as long as Mg: 0.03 % or less, Ca: 0.03 % or less, P: 0.05 % or less, S: 0.001 % or less, and Cu: 2 % or less.

[0030] The low thermal expansion Ni-base superalloy according to the invention can be prepared by the same method as a conventional method for preparing Ni-base superalloy. The heat treatment, after solid-solution heat treatment not less than 950°C, is effective in a single step aging (700 to 850 °C) and a two-step aging (first step : 800 to 900 °C, second step : 700 to 800 °C).

50 Examples

[0031] Various examples of the present invention will be explained below.

55 **[0032]** The alloy having the compositions as shown in Table 1 was molten in a vacuum induction furnace having a capacity of 50 kg and its ingot having 50 kg was cast. The surface of an ingot of the ingot was cut away and the ingot was heat-treated for 15 hr at 1150 °C as a homogenizing treatment. Thereafter, the ingot was forged into rods each having 60 mm square. The forged rods were heated for 2 hr at 1100 °C, and thereafter water-cooled for its solid solution. The rods were hardening-treatment aged for 16 hr at 750 °C. Sample pieces cut out from the rods were subjected to

various tests. Thus, the test results as shown in Table 2 were obtained.

[0033] As regards the thermal expansion coefficient, using quartz as a standard sample, the average thermal expansion coefficient from room temperature to 70 °C was measured by a dilatometer available from RIGAKU DENSI CO. LTD. The measurement was carried out under the condition of a temperature rising speed of 5 °C/min on the basis of a differential dilatometry. The sample used has a size of $\phi 5 \times L19$.

[0034] The high temperature tensile test was carried out for a tensile specimen with ridges having a parallel portion of 6 mm in diameter at 700 °C on the basis of the JIS high temperature tensile test method.

[0035] The creep rupture test was carried out for a specimen with a parallel portion having 6.4 mm in diameter at 700 °C under load stress of 343 MPa.

[0036] The steam oxidation test which is problematic in a steam turbine was carried out for the specimen having a width of 10 mm, length of 10 mm and thickness of 5 mm for 100 hr at 600 °C, thereby measured the weight gain of oxidation after the test. The test was carried out in an environment of atmospheric pressure, water-vapor concentration of 83 % and a water-steam flow rate of 7.43 l/s.

Table 1:

No.	C	Si	Mn	Ni	Fe	Co	Cr	Re	W	Mo	Ta	Nb	Al	Ti	Zr	B	Mo+(W+Re)/2	Al+Ti+Nb+Ti
1	0.11	0.19	0.42	*	6.91		7.75	2.08	5.03	10.51			0.80	2.30		0.006	14.07	4.8
2	0.02	0.08	0.09	*	0.41		6.14		5.10	13.61			0.81	2.35		0.004	16.18	5.0
3	0.06	0.11	0.12	*	0.61		6.93		5.11	11.93			0.26	2.88	0.06	0.011	14.49	4.3
4	0.06	0.15	0.25	*	0.47		12.01			19.25			1.81	0.91		0.008	19.25	5.2
5	0.02	0.31	0.21	*	0.96		14.11			17.08			0.70	2.40	0.04	0.004	17.08	4.6
6	0.05	0.09	0.12	*	0.21		18.12			17.21			0.51	1.98	0.03	0.003	17.21	3.6
7	0.06	0.11	0.12	*	0.48		10.12		4.92	17.51			0.48	2.42	0.06	0.011	19.97	4.3
8	0.04	0.08	0.09	*	1.02		11.91			19.07			0.61	3.21	0.03	0.005	19.07	5.5
9	0.06	0.09	0.25	*	0.62		10.51		12.13	8.24			0.39	2.48		0.008	14.31	4.3
10	0.03	0.25	0.36	*	0.43	3.91	9.52		4.17	13.23		0.6	0.90	2.20	0.05	0.004	15.32	5.3
11	0.03	0.06	0.06	*	0.54	1.92	7.16		4.96	15.04			1.11	1.65	0.03	0.005	17.52	4.7
12	0.05	0.06	0.11	*	0.36	2.14	10.12		4.12	19.18		0.7	1.10	1.61	0.03	0.004	21.24	5.2
13	0.05	0.09	0.09	*	0.41	4.42	11.91		4.96	13.94	0.6	0.8	0.39	2.79	0.05	0.006	16.42	5.3
14	0.04	0.21	0.42	*	0.97		7.82		4.21	19.11			1.20	1.60	0.05	0.003	21.22	4.9
15	0.04	0.05	0.08	*	0.51		9.03	1.11	3.90	18.67			0.80	2.30	0.02	0.006	21.18	4.9
16	0.03	0.07	0.10	*	0.34		7.11		4.08	20.12			1.05	1.71	0.04	0.003	22.16	4.7
17	0.02	0.09	0.09	*	0.51		9.01		4.90	17.01			0.45	2.01	0.05	0.007	19.46	3.7
18	0.04	0.09	0.08	*	0.84		8.17		4.01	14.06			0.75	3.51	0.04	0.004	16.07	6.3
19	0.02	0.09	0.11	*	0.21		9.01		5.10	17.12	0.5	0.5	0.51	2.41	0.03	0.003	19.67	4.9
20	0.03	0.10	0.08	*	0.32		9.10		4.95	16.51		0.5	0.49	2.51	0.03	0.002	18.99	4.8
21	0.02	0.12	0.13	*	0.24		12.13			19.13		0.5	0.38	2.49	0.03	0.003	19.13	4.4
22	0.03	0.11	0.21	*	0.12		9.13		5.01	16.91			0.38	3.61	0.03	0.002	19.42	5.7
23	0.03	0.09	0.12	*	0.24		9.23			17.12		0.5	0.35	3.54	0.03	0.002	17.12	5.7
C1	0.12	0.04	0.72	*	*		10.51		1.72	0.51		0.1	1.41	2.46		V:0.2	1.37	
C2	0.04	0.11	0.09	*	0.91		15.11						0.21	2.81		0.004		5.8
C3	0.04	0.21	0.32	*	0.41	18.92	18.12		2.86			3	5.39	0.21		0.003	2.86	3.8
C4	0.03	0.07	0.08	*	24.51	35.30	3.21					4.7	0.03	1.48		0.003		13.0
C5	0.03	0.09	0.07	*	41.80	13.02							0.03	1.48		0.003		4.8
C6	0.04	0.09	0.08	*	0.23		9.12		13.10	7.92			2.41	2.51	0.04	0.003	14.47	9.0
C7	0.03	0.09	0.12	*	0.35		11.23		13.70	7.50			1.51	3.24	0.05	0.004	14.35	7.9
C8	0.04	0.09	0.12	*	0.87		13.12		1.41	8.12			0.42	2.51	0.05	0.004	8.83	4.0
C9	0.03	0.08	0.11	*	0.41		14.12		8.20	23.5			0.56	2.51	0.04	0.003	27.62	4.8
C10	0.04	0.11	0.12	*	0.21		10.12		4.11	15.86			0.36	1.12	0.05	0.003	17.92	2.3

C1 to C10: Comparative Examples.

*: Remainder

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Table 2

5		Room temperature to 700°C average thermal expansion coefficient ($\times 10^{-6}/^{\circ}\text{C}$)	700°C Tensile strength (MPa)	700°C/343MPa creep rupture life (hr)	600°Cx500hr weight gain of steam oxidation (mg/cm ²)
	1	13.4	900	1513	0.17
10	2	12.9	915	1625	0.16
	3	13.1	933	1012	0.16
	4	13.2	928	1131	0.09
15	5	13.8	996	1025	0.08
	6	13.4	958	894	0.05
	7	12.7	1001	1341	0.16
	8	13.0	1109	981	0.15
20	9	12.9	896	1532	0.21
	10	13.3	931	835	0.15
	11	12.9	890	1019	0.16
25	12	12.8	996	1216	0.11
	13	12.7	1014	2531	0.11
	14	12.7	970	1083	0.12
	15	12.7	1017	899	0.11
30	16	12.5	980	1395	0.13
	17	12.8	930	791	0.14
	18	12.9	1069	2482	0.16
35	19	12.4	1007	2780	0.13
	20	12.8	999	1987	0.15
	21	13.1	1014	2108	0.11
	22	12.5	1118	2880	0.16
40	23	13.1	1078	2541	0.14
	C1	12.4	178		3.19
45	C2	14.5	771	1011	0.17
	C3	16.1	774	1697	0.16
	C4	13.0	922	422	1.90
	C5	11.3	956	398	2.38
50	C6				
	C7				
	C8	14.1	866	768	0.12
	C9				
55	C10	13.0	641	501	0.18
C1 to C10: Comparative Examples					

[0037] As understood from the results shown in Table 2, all the samples according to the invention have the average thermal expansion coefficient of $14.0 \times 10^{-6}/^{\circ}\text{C}$ or less at the temperature from room temperature to 700°C , and the tensile strength of 890 to 1118 MPa at 700°C . They have the creep rupture life of 791 to 2880 hr, and the weight gain of steam oxidation of 0.05 to 0.21 mg/cm².

[0038] On the other hand, comparative example No. 1, which is 12 Cr ferritic steel, has a low average thermal expansion coefficient of $12.4 \times 10^{-6}/^{\circ}\text{C}$. However, its high temperature tensile strength is lower than the samples according to the invention. Comparative examples Nos. 2 and 3, which are Nimonic 80A and Refractaloy 26 known as a high temperature bolt material. These alloys have average thermal expansion coefficients of $14.5 \times 10^{-6}/^{\circ}\text{C}$ and $16.1 \times 10^{-6}/^{\circ}\text{C}$, respectively which are higher than those of the samples according to the invention. Comparative examples Nos. 4 and 5, which are Inconel 783 and Incoloy 909, have average thermal expansion coefficients which are equal or lower than those of the samples according to the invention, but have worse steam oxidation characteristics than those according to the invention.

[0039] Comparative example No. 6, which has an Al content exceeding the upper limit of the invention and a total quantity of Al + Ti exceeding the upper limit of the invention, produced a crack in the material by water-cooling during the solid solution heat treatment. Comparative example No. 7, which has a total quantity of Al + Ti exceeding the upper limit of the invention, like the comparative example No. 6, produced a crack in the material by water-cooling during the solid solution heat treatment, and hence could not be evaluated thereafter.

[0040] Comparative example No. 8, which is an alloy containing more Cr and a smaller value of $\text{Mo} + 1/2 (\text{W} + \text{Re})$ than those of the samples according to the invention, has a larger average thermal expansion coefficient of $14.1 \times 10^{-6}/^{\circ}\text{C}$ than those of the samples according to the invention.

[0041] Comparative example No. 9, which is an alloy having a larger value of $\text{Mo} + 1/2 (\text{W} + \text{Re})$, has worse forgeability. This alloy produced a crack during the forging and could not be evaluated thereafter.

[0042] Comparative example No. 10, which is lower in the total of Al + Ti than in the invention and insufficient in the precipitation amount of γ' phase, has a smaller high-temperature strength than those of the samples according to the invention.

[0043] The low thermal expansion Ni-base superalloy according to the invention, which has the compositions as shown, has the average thermal expansion coefficient of $14.0 \times 10^{-6}/^{\circ}\text{C}$ which is approximately equal to that of 12 Cr ferritic steel, and also has the creep rupture life of 791 to 2880 hr and weight gain of steam oxidation of 0.05 to 0.21 mg/cm². Thus, the Ni-base superalloy according to the invention has an excellent effect of the high temperature strength and corrosion/oxidation resistance where are approximately equal to those of the austenite heat-resistant alloy.

[0044] The low thermal expansion Ni-base superalloy can be applied to the bolt, blade and disk of a steam turbine, gas turbine and jet engine, and also applied to a boiler tube of a heating machine and pressurizing machine, thereby giving an excellent effect of improving the reliability of a thermal power plant.

Claims

1. A low thermal expansion Ni-base superalloy comprising, by weight % (hereinafter the same as long as not particularly defined),

C: 0.15% or less;
Si: 1% or less;
Mn: 1% or less;
Cr: 5 to 20 %;
at least one of Mo, W and Re of $\text{Mo} + 1/2 (\text{W} + \text{Re})$ of 10 to 25%;
Al: 0.2 to 2%;
Ti: 0.5 to 4.5%;
Fe of 10% or less;
at least one of B: 0.02% and Zr: 0.2% or less;
a remainder of Ni and inevitable impurities;

wherein the atomic % of Al + Ti is 2.5 to 7.0.

2. The low thermal expansion Ni-base superalloy according to claim 1, wherein the amount of Cr is from 5 to 10% (exclusive).

3. The low thermal expansion Ni-base superalloy according to one of claims 1 or 2, wherein the amount of at least one of Mo, W and Re of $\text{Mo} + 1/2 (\text{W} + \text{Re})$ is from 17 (exclusive) to 25%.

4. The low thermal expansion Ni-base superalloy according to any one of the preceding claims, wherein the amount of Al is from 0.2 to 0.4% (exclusive).
- 5 5. The low thermal expansion Ni-base superalloy according to any one of the preceding claims, wherein the amount of Ti is from 3.5 (exclusive) to 4.5%.
6. The low thermal expansion Ni-base superalloy according to any one of the preceding claims, further comprising at least one of Nb and Ta in Nb + 1/2 Ta: 1.5% or less; wherein the atomic % of Al + Ti + Nb + Ta is 2.5 to 7.0.
- 10 7. The low thermal expansion Ni-base superalloy according to any one of claims 1 to 6, wherein a part of Ni is replaced by Co of 5% or less.
8. The low thermal expansion Ni-base superalloy according to any one of claims 1 to 7, wherein an average expansion coefficient at a temperature from room temperature to 700°C is $14.0 \times 10^{-6}/^{\circ}\text{C}$ or less.

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EUROPEAN SEARCH REPORT

Application Number
EP 00 10 4667

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