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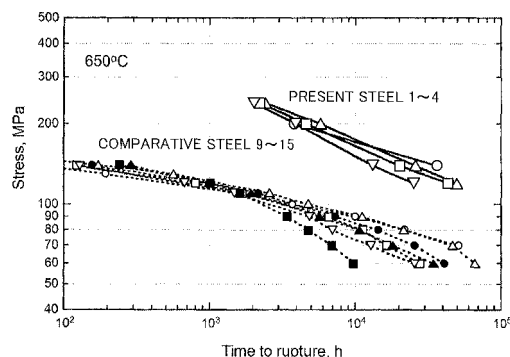
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(54) **FERRITIC Cr-STEEL FOR HEAT-RESISTANT PRECISION COMPONENT AND METHOD FOR PRODUCING SAME, AND HEAT-RESISTANT PRECISION COMPONENT AND METHOD FOR PRODUCING SAME**

(57) A ferritic Cr-steel for a heat-resistant precision component contains Cr in an amount of from 13% by mass to 30% by mass, and has a thermal expansion coefficient of 15×10^{-6} or less in a temperature range of from room temperature to 800°C, and a minimum creep rate of 1×10^{-4} /h or less at 700°C under stress of 100 MPa. The ferritic Cr-steel for a heat-resistant precision component is produced by hot working a ferritic Cr-steel in a temperature range of 850 to 1,200°C, forming the ferritic Cr-steel into a predetermined shape, subjecting the steel to an annealing treatment in a temperature range of 1,000 to 1,250°C, and cooling the steel to 400°C or less at a cooling rate of 100°C/min or higher. The production of the ferritic Cr-steel realizes a heat-resistant precision component, such as the rotor, disc, and blade of a turbine, that can withstand use under high temperatures above 600°C.

Fig.2



Description

Technical Field

5 **[0001]** The present invention relates to ferritic Cr-steel used as material of precision components that have heat resistance.

Background Art

10 **[0002]** Ferritic Cr-steel (also called ferritic high Cr-steel) is generally used as material of precision components that have heat resistance (hereinafter, referred to as "heat-resistant precision components), for example, such as the rotors, discs, and blades of machines such as steam turbines and gas turbines used under high temperature, because large thermal expansion coefficient differences cause positional misalignment relative to the other components.

15 **[0003]** However, in face of the recent demand for use of turbines under high temperatures above 650°C, a Ni-based superalloy has been proposed as material of heat-resistant precision components, as described in Patent Document 1.

[0004] This is because the ferritic Cr-steel, which undergoes small dimensional changes by thermal expansion, has low high-temperature strength, and undergoes creep deformation and changes the shape of the precision component.

[0005] However, the physical properties of the Ni-based superalloy do not allow the thermal expansion coefficient to be kept at values below that of the ferritic Cr-steel. In fact, further improvement in heat resistance tends to increase the thermal expansion coefficient.

[0006] Indeed, there is a dilemma that the ferritic Cr-steel, with its small thermal expansion coefficient, has large creep deformation, and that the Ni-based superalloy, with its small creep deformation and high high-temperature strength, has a large thermal expansion coefficient.

25 **[0007]** Accordingly, it is considered very difficult to realize a heat-resistant precision component that can withstand use under high temperatures above 650°C while undergoing only small changes in shape and dimension.

[Patent Document 1] JP-A-2007-332412

Disclosure of Invention

30 Problems that the Invention is to Solve

[0008] The present invention has been made under these circumstances, and it is an object of the present invention to provide a ferritic Cr-steel for a heat-resistant precision component and a producing process thereof, and a heat-resistant precision component and a producing process thereof, with which heat resistance can be improved while providing low thermal expansion properties.

Means for Solving the Problems

40 **[0009]** In order to solve the foregoing problems, the present invention provides a ferritic Cr-steel for a heat-resistant precision component,

characterized in that the ferritic Cr-steel is of a chemical composition that mainly includes, in % by mass,

Cr: 13 to 30%,

Ni: 1×10^{-1} to 2.5%,

C: 1×10^{-3} to $1 \times 10^{-1}\%$, and

45 N: 1×10^{-3} to $1 \times 10^{-1}\%$,

wherein the ferritic Cr-steel allows for inclusion of an additional component and unavoidable impurities, includes Fe as the remaining part, and forms a ferrite phase.

[0010] It is preferable in the ferritic Cr-steel for a heat-resistant precision component that Ni be added in an amount that satisfies the relationship $Ni > 10(C + N)$, where Ni, C, and N each represent the amount of each component added (in % by mass), when C is added in $1 \times 10^{-2}\%$ by mass or more and/or Ni is added in $1 \times 10^{-2}\%$ by mass or more.

[0011] It is preferable in the ferritic Cr-steel for a heat-resistant precision component that the ferrite phase be 70 volume% or more.

[0012] It is preferable that the additional component be one or more of the following in % by mass,

Mo: 5×10^{-1} to 5%,

55 W: 5×10^{-1} to $1 \times 10\%$,

V: 5×10^{-2} to $4 \times 10^{-1}\%$,

Nb: 1×10^{-2} to $1 \times 10^{-1}\%$,

Co: 1×10^{-1} to $1 \times 10\%$, and

B: 2×10^{-3} to $4 \times 10^{-3}\%$, and

that at least one of carbide, nitride, and intermetallic compound be precipitated in crystal grains.

[0013] It is preferable in the ferritic Cr-steel for a heat-resistant precision component that Mo and W be added in amounts that satisfy the relationship $\text{Mo} + 0.5\text{W} \geq 3.0\%$ by mass, where Mo and W each represent the amount of each component added (in % by mass).

[0014] The present invention also provides a ferritic Cr-steel for use in a heat-resistant precision component and that contains Cr in an amount of from 13% by mass to 30% by mass,

[0015] characterized in that the ferritic Cr-steel has a thermal expansion coefficient of 15×10^{-6} or less in a temperature range of from room temperature to 800°C, and a minimum creep rate of $1 \times 10^{-4}/\text{h}$ or less at 700°C under stress of 100 MPa.

[0016] The present invention also provides a process for producing a ferritic Cr-steel for a heat-resistant precision component,

the process including hot working the ferritic Cr-steel of the foregoing chemical composition in a temperature range of 850 to 1,200°C, forming the ferritic Cr-steel into a predetermined shape, subjecting the steel to an annealing treatment in a temperature range of 1,000 to 1,250°C, and cooling the steel to 400°C or lower at a cooling rate of 100°C/min or higher.

[0017] The present invention also provides a heat-resistant precision component formed from the ferritic Cr-steel for a heat-resistant precision component.

[0018] The heat-resistant precision component may be any one of a rotor, a disc, and a blade of a turbine.

[0019] The present invention also provides a process for producing a heat-resistant precision component, the process including hot working the ferritic Cr-steel of the foregoing chemical composition in a temperature range of 850 to 1,200°C, forming the ferritic Cr-steel into a component shape, subjecting the steel to an annealing treatment in a temperature range of 1,000 to 1,250°C, and cooling the steel to 400°C or less at a cooling rate of 100°C/min or higher.

Advantage of the Invention

[0020] The ferritic Cr-steel for a heat-resistant precision component and the producing process thereof, and the heat-resistant precision component and the producing process thereof of the present invention realize a heat-resistant precision component for mechanical structures, as represented by turbines, used under high temperature. The heat-resistant precision component has high heat resistance (creep strength) while maintaining optimum low thermal expansion properties.

Brief Description of Drawings

[0021]

FIG. 1 is a graph representing the influence of cooling rate on creep rupture time at 650°C.

FIG. 2 is a graph representing the results of a creep test performed at 650°C.

FIG. 3 is a graph representing the relationship between creep rate and time at 700°C under stress of 100 MPa.

FIG. 4 is a graph representing the relationship between creep rate and time at 750°C under stress of 50 MPa.

FIG. 5 is a graph representing creep rupture time at 750°C.

FIG. 6 is a graph representing the temperature dependence of linear expansion coefficient.

Mode for Carrying Out the Invention

[0022] The ferritic Cr-steel for a heat-resistant precision component of the present invention is a material used for components of mechanical structures such as turbines, and that has excellent high temperature strength, heat resistance, oxidation resistance, and high toughness even at high temperatures above 650°C (here and below, the temperature is represented in units of 50°C), and that can withstand use under high temperature and high pressure for extended time periods while undergoing only a limited decrease in strength.

[0023] The ferritic Cr-steel for a heat-resistant precision component is produced by hot working a ferritic Cr-steel ingot in a temperature range of 850 to 1,200°C and forming the ferritic Cr-steel into a predetermined shape, and then subjecting the steel to an annealing treatment in a temperature range of 1,000 to 1,250°C, and cooling the steel to 400°C or less at a cooling rate of 100°C/min or higher.

[0024] The hot working temperature such as in hot forging is 850 to 1,200°C, preferably 950 to 1,150°C, more preferably 1,000 to 1,100°C. Above the upper limit temperature, an abrupt decrease in ductility may occur. Below the lower limit temperature, deformation resistance increases, which may lead to processing defects such as cracking.

[0025] The temperature of the annealing treatment is 1,000 to 1,250°C, preferably 1,000 to 1,200°C, more preferably 1,050 to 1,200°C. Above the upper limit temperature, serious coarsening of crystal grains may occur, which can be

detrimental to various properties of the steel, including toughness, ductility, and weldability. Below the lower limit temperature, it may not be possible to completely melt the steel and to exhibit a sufficient strength.

[0026] Temperatures of 400°C and higher may cause precipitation of a second phase in the process of cooling from the annealing temperature, because of the fast precipitation rate of second-phase compounds such as carbides, nitrides, and intermetallic compounds. In order to control such precipitation of the second phase, the cooling rate of the cooling to 400°C or less following the annealing treatment is 100°C/min or higher, preferably 120°C/min or higher, more preferably 150°C/min or higher. Below the lower limit, a coarse second phase may precipitate at the crystal grain boundary during the cooling process, and it becomes difficult to disperse and precipitate a fine second phase in the crystal grains. In this case, sufficient strength may not be developed because of the failure to effectively control the precipitation state of the second phase for strength improvement.

[0027] The ferritic Cr-steel for a heat-resistant precision component produced as above has a linear expansion coefficient of 15×10^{-6} or less in a temperature range of from room temperature to 850°C. Above the upper limit, the amounts of thermal expansion and contraction at the start-up and stopping of a turbine increase, and it becomes difficult to produce heat-resistant precision components with high dimension accuracy.

[0028] Further, the ferritic Cr-steel for a heat-resistant precision component has a minimum creep rate of 1.0×10^{-4} /h or less, preferably 1.0×10^{-5} /h or less at 700°C under stress of 100 MPa. A minimum creep rate exceeding the upper limit increases creep deformation that depends on the load generated during the operation of a turbine, and causes the rotation component rotor blade (blade) to contact the stationary components stator vane (vane) and vessel (casing) of the turbine, with the result that damage or other defects may occur.

[0029] Further, the ferritic Cr-steel for a heat-resistant precision component has a creep rupture time of preferably 1,000 hr or more at 750°C under stress of 80 MPa, 5,000 hr or more at 750°C under stress of 50 MPa, and 10,000 hr or more at 750°C under stress of 30 MPa. A creep rupture time below the lower limit shortens the creep rupture lifetime that depends on the load generated during the operation of a turbine, and may thus present difficulties in ensuring a sufficient creep rupture lifetime in practical applications.

[0030] The ferritic Cr-steel before forming into a shape, in the form of, for example, a steel ingot to be subjected to hot working is a ferritic Cr-steel, or a ferritic high Cr-steel as it is called, whose chemical composition is adjusted to include the components below (here and below, % means % by mass).

(1) C: 1×10^{-3} to $1 \times 10^{-1}\%$

[0031] C needs to be added in at least $1 \times 10^{-3}\%$ to improve creep strength. The upper limit of the C additive amount is $1 \times 10^{-1}\%$, because the excess addition lowers toughness. When C is added in $1 \times 10^{-2}\%$ or more, it is preferable that $Ni > 10 (C + N)$, where Ni, C, and N each represent the additive amount of each component (in % by mass).

(2) Cr: 13 to 30%

[0032] It is essential that Cr be added in 13% or more. In actual practice, Cr is added in preferably 13.5% or more to ensure a 70 volume% or more of the ferrite phase, and to improve oxidation resistance. The upper limit of Cr additive amount is 30%, because a Cr additive amount in excess of 30% notably lowers toughness.

(3) N: 1×10^{-3} to $1 \times 10^{-1}\%$

[0033] N needs to be added in at least $1 \times 10^{-3}\%$ to improve creep strength. The upper limit of N additive amount is $1 \times 10^{-1}\%$, because the excess addition lowers toughness. When N is added in $1 \times 10^{-2}\%$ or more, it is preferable that $Ni > 10 (C + N)$, as with the case of C.

(4) Ni: 1×10^{-1} to 2.5%

[0034] Ni needs to be added in at least $1 \times 10^{-1}\%$ to improve toughness. When C and/or N are added in $1 \times 10^{-2}\%$ or more, it is preferable that the Ni additive amount satisfy $Ni > 10 (C + N)$ to ensure toughness, as above. The upper limit of Ni additive amount is 2.5%, because the excess addition lowers the percentage volume of the ferrite phase.

[0035] As presented in Table 2 below, comparative steels 7 and 8 with the Ni additive amount satisfying $Ni \leq 10 (C + N)$ (Ni, C, and N each represent the additive amount of each component (in % by mass)) have small Charpy impact values, regardless of the cooling rate. On the other hand, the water-cooled materials of the steels 1 to 4 of the present invention satisfying the relationship $Ni > 10 (C + N)$ have sufficiently greater Charpy impact values than those of the comparative steels 7 and 8.

[0036] The ferritic Cr-steel can be strengthened with the controlled precipitation of at least one of carbide, nitride, and intermetallic compound, specifically, by the fine dispersion and precipitation within the crystal grains. This is effective

for improving creep strength. To this end, the ferritic Cr-steel allows for addition of the components below in its chemical composition, in addition to the foregoing components.

(5) Mo: 5×10^{-1} to 5%

[0037] Mo is a chemical component effective for precipitating an intermetallic compound, and can improve creep strength. Mo may be added in $5 \times 10^{-1}\%$ or more. The upper limit of Mo additive amount is preferably 5%, because the excess addition may lower toughness.

(6) W: 5×10^{-1} to $1 \times 10\%$

[0038] As with Mo, W is a chemical component effective for precipitating an intermetallic compound, and can improve creep strength. W may be added in $5 \times 10^{-1}\%$ or more. The upper limit of W additive amount is preferably $1 \times 10\%$, because the excess addition may lower toughness.

[0039] Note that Mo and W may be added to satisfy the relationship $\text{Mo} + 0.5\text{W} \geq 3.0\%$ (Mo and W each represent the additive amount (in % by mass)), so as to ensure a sufficient amount of intermetallic compound precipitation.

(7) V: 5×10^{-2} to $4 \times 10^{-1}\%$

[0040] V forms carbides or nitrides effective for improving creep strength. V may be added in $5 \times 10^{-2}\%$ or more. The upper limit of V additive amount is preferably $4 \times 10^{-1}\%$, because the excess addition is not necessarily effective for the formation of carbides and nitrides.

(8) Nb: 1×10^{-2} to $1 \times 10^{-1}\%$

[0041] As with V, Nb forms carbides or nitrides effective for improving creep strength. Nb may be added in $1 \times 10^{-2}\%$ or more. The upper limit of Nb additive amount is preferably $1 \times 10^{-1}\%$, because the excess addition is not necessarily effective for the formation of carbides and nitrides.

(9) Co: 1×10^{-1} to $1 \times 10\%$

[0042] Co is a component effective for miniaturizing the precipitated carbide, nitride, and intermetallic compound, and for improving creep strength. Co may be added in $1 \times 10^{-1}\%$ or more. The upper limit of Co additive amount is preferably $1 \times 10\%$, because the excess addition may lower the percentage volume of the ferrite phase.

(10) B: 2×10^{-3} to $4 \times 10^{-3}\%$

[0043] B is a component effective for miniaturizing and stabilizing the precipitates, and for strengthening the grain boundary. B may be added in $2 \times 10^{-3}\%$ or more. The upper limit of B additive amount is preferably $4 \times 10^{-3}\%$, because the excess addition may lead to formation of boron nitride, and may not be necessarily effective for improving creep strength.

(11) Mn: 5×10^{-2} to $8 \times 10^{-1}\%$

[0044] Mn is a component effective as a deoxidant. Mn may be added in $5 \times 10^{-2}\%$ or more. The upper limit of Mn additive amount is preferably $8 \times 10^{-1}\%$, because the excess addition is detrimental to strength and toughness.

(12) Si: 5×10^{-2} to $5 \times 10^{-1}\%$

[0045] Si is a component effective as a deoxidant. Si may be added in $5 \times 10^{-2}\%$ or more. The upper limit of Si additive amount is preferably $5 \times 10^{-1}\%$, because the excess addition accelerates the coarsening of the precipitates and lowers strength.

[0046] The remaining parts of the chemical composition of the ferritic Cr-steel for a heat-resistant precision component are Fe and unavoidable impurities.

[0047] Preferably, the ferritic Cr-steel for a heat-resistant precision component forms at least 70 volume% of the ferrite phase to improve creep strength. A tempered martensite structure is unstable at high temperatures, whereas the ferrite phase has high structure stability at high temperatures. As presented in Table 2, furnace cooling of the steels 2 to 4 of the present invention makes the percentage volume of the ferrite phase less than 70% because of the slow cooling rate

following the annealing treatment. However, the percentage volume of the ferrite phase becomes 70% or more when the cooling rate down to 400°C or less is 100°C/min or higher in water cooling. Thus, as represented in FIG. 1, the water-cooled materials of the steels 2 to 4 of the present invention have creep rupture times about 10 times longer than those of the furnace cooled materials.

[0048] Further, as presented in FIG. 2, the steels 1 to 4 of the present invention have longer creep rupture times than the comparative steels 9 to 15 in which the Cr additive amount is less than 13% and the percentage volume of the ferrite phase is less than 70%.

[0049] Examples are described below.

[0050] In the following Examples, a round bar was assumed to be a component, and various properties were measured. It would be easily anticipated and understood that precision components, such as the rotor, disc, and blade of a turbine, produced from the ferritic Cr-steel has properties comparable to those of the ferritic Cr-steel used as the material.

Examples

[0051] The round bars of steels 1 to 8 with the chemical compositions presented in Table 1 (steels 1 to 6 of the present invention, and comparative steels 7 and 8) were each prepared from a 10-kg steel ingot subjected to 850 to 1,150°C hot forging to have a diameter of 15 mm. After 1,200°C annealing treatment, each specimen was cooled by furnace cooling or water cooling.

[0052] Note that Table 1 also presents the chemical compositions of the existing ferritic heat-resistant steels (steels 9 to 15; comparative steels).

Table 1

Specimen No.	Component (Mass%)										
	C	Si	Mn	Ni	Cr	Mo	V	Nb	W	Co	N
1	0.051	0.20	0.50	1.99	14.94	0.99	0.20	0.051	6.05	0.01	0.041
2	0.049	0.20	0.51	1.21	15.02	1.00	0.20	0.051	6.04	2.96	0.042
3	0.048	0.21	0.51	1.60	15.00	1.00	0.20	0.050	6.03	2.95	0.044
4	0.048	0.23	0.51	2.00	14.96	0.99	0.20	0.050	6.07	2.98	0.036
5	0.047	0.21	0.51	0.42	14.93	1.00	0.20	0.050	6.05	2.96	0.041
6	0.048	0.20	0.51	0.78	15.00	1.00	0.20	0.050	6.05	2.96	0.042
7	0.110	0.24	0.49	0.02	15.21	0.98	0.20	0.051	2.95	-	0.072
8	0.100	0.20	0.48	-	14.88	1.01	0.19	0.045	6.01	2.96	0.002
9	0.110	0.10	0.41	0.17	9.26	0.42	0.16	0.057	1.67	-	0.046
10	0.098	0.29	0.42	0.13	9.50	0.36	0.19	0.062	1.74	-	0.046
11	0.120	0.28	0.61	0.34	10.50	0.36	0.21	0.060	2.05	-	0.069
12	0.140	0.26	0.65	0.40	11.03	0.29	0.20	0.070	1.95	-	0.064
13	0.120	0.30	0.60	0.32	10.65	0.34	0.19	0.050	1.89	-	0.054
14	0.130	0.31	0.60	0.36	10.65	0.33	0.19	0.050	1.87	-	0.057
15	0.110	0.27	0.59	0.33	12.10	0.34	0.19	0.060	1.82	-	0.066

[0053] These test pieces were subjected to a Charpy impact test at 100°C. The results are presented in Table 2.

[0054] Impact value was smaller in comparative steels 7 and 8 in which Ni was added in small amounts outside the range for the steels of the present invention, regardless of the cooling rate after the annealing treatment. In contrast, the steels 1 to 4 of the present invention had greater impact values of 300 J/cm² or more than the furnace cooled materials and comparative steels 7 and 8 in water cooling with a high cooling rate, though the values were small in furnace cooling that involves a lower cooling rate.

Table 2

Specimen No.	Impact value at 100°C (J/cm ²)		Percentage volume of ferrite phase (%)		Remarks
	Furnace cooling	Water cooling	Furnace cooling	Water cooling	
1	6	300	94	100	
2	6	333	56	83	
3	5	367	48	77	
4	6	366	40	72	
7	12	32	100	100	Out of Ni range, Out of Co range
8	5	12	-	91	Out of Ni range

[0055] FIG. 1 is a graph representing the influence of cooling rate on creep rupture time at 650°C in the steels 2 to 4 of the present invention. It can be seen that the water-cooled materials with a high cooling rate have creep rupture times about 10 times longer than those of the furnace cooled materials involving a low cooling rate.

[0056] Table 3 represents the measured data used to create FIG. 1.

Table 3

Stress (MPa)	Creep rupture time at 650°C (hr)					
	The present steel 2		The present steel 3		The present steel 4	
	Water cooling	Furnace cooling	Water cooling	Furnace cooling	Water cooling	Furnace cooling
240	2405	-	2222	-	2008	-
200	5789	-	4620	-	3911	-
140	25776	1507	20074	1478	13211	1810
120	49380	2883	43299	3063	25076	3508

[0057] It was confirmed that the required cooling rate conditions include an annealing treatment within a temperature range of 1,000 to 1,250°C, and the subsequent cooling to 400°C--a temperature that essentially does not allow for precipitation of carbides, nitrides, and intermetallic compounds--at a high cooling rate that can suppress the precipitation of these components, specifically at 100°C/min or higher.

[0058] FIG. 2 is a graph representing the results of a creep test at 650°C.

[0059] It can be seen that the steels 1 to 4 of the present invention have higher creep strengths than comparative steels 9 to 15 in which Cr is added in less than 13% by mass, and in which the percentage volume of the ferrite phase is less than 70%.

[0060] Table 4 represents the measured data used to create FIG. 2.

Table 4

Stress (MPa)	Creep rupture time at 650°C (hr)										
	The present steel				Comparative steel						
	1	2	3	4	9	10	11	12	13	14	15
240	-	2405	2222	2008	-	-	-	-	-	-	-
200	3834	5789	4620	3911	-	-	-	-	-	-	-
180	-	-	-	-	-	6	-	-	-	-	-
160	-	-	-	-	11	20	-	-	-	-	-

(continued)

Stress (MPa)	Creep rupture time at 650°C (hr)										
	The present steel				Comparative steel						
	1	2	3	4	9	10	11	12	13	14	15
140	36418	25776	20074	13211	66	171	122	127	157	289	241
130	-	-	-	-	194	564	-	-	-	-	-
120	-	49380	43299	25076	-	-	804	670	985	1004	1008
110	-	-	-	-	1689	2589	1670	1478	2171	1934	1615
100	-	-	-	-	3739	4831	-	-	-	-	-
90	-	-	-	-	10002	11219	6473	4853	7249	5721	3412
80	-	-	-	-	21717	21505	11283	6966	14462	10713	4783
70	-	-	-	-	50871	46437	16377	12802	25632	18158	6909
60	-	-	-	-	-	65959	27733	25438	40713	34223	9734

[0061] FIG. 3 is a graph representing the relationship between creep rate and time at 700°C under stress of 100 MPa.

[0062] It can be seen that the creep rates of the steels 2 and 4 of the present invention are only about 1/1,000 of the creep rates of comparative steels 9 to 11, and that the creep rupture times are at least about 100 times longer.

[0063] Table 5 represents the minimum creep rates obtained from FIG. 3. The steels 2 and 4 of the present invention have a minimum creep rate of 1.0×10^{-4} /h or less, or 1.0×10^{-5} /h or less.

Table 5

700°C, Stress 100 MPa	
Tested material	Minimum creep rate (h ⁻¹)
The present steel 2	2.0×10^{-6}
The present steel 4	1.9×10^{-6}
Comparative steel 9	2.1×10^{-3}
Comparative steel 10	1.1×10^{-3}
Comparative steel 11	2.5×10^{-3}

[0064] FIG. 4 is a graph representing the relationship between creep rate and time at 750°C under stress of 50 MPa.

[0065] The steel 4 of the present invention did not rupture during the course of testing. The creep rates of the steels 2 and 4 of the present invention were only 1/100 or less of the creep rates of comparative steels 9 and 13, and the creep rupture times were at least about 100 times longer.

[0066] Table 6 represents the measured data used to create FIG. 4.

Table 6

750°C, Stress 50 MPa	
Tested material	Minimum creep rate (h ⁻¹)
The present steel 2	1.1×10^{-6}
The present steel 4	7.4×10^{-7}
Comparative steel 9	5.3×10^{-4}
Comparative steel 13	5.2×10^{-4}

[0067] FIG. 5 is a graph representing creep rupture time at 750°C.

[0068] The steels 2 and 4 of the present invention did not rupture during the course of testing under stresses of 50 MPa and 30 MPa. Further, the steels 2 and 4 of the present invention tested under stresses of 80 to 50 MPa had creep rupture times at least about 100 times longer than the rupture times of comparative steels 9 to 15. It can also be seen that the creep rupture times are longer than those of the austenite heat-resistant steels 21 to 28 (SUS316) presented in Table 7. Further, it can be seen that, even under stress of 30 MPa, the steels 2 and 4 of the present invention have creep rupture times comparable to that of SUS316.

[0069] Table 7 represents the measured data used to create FIG. 5.

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55 50 45 40 35 30 25 20 15 10 5

Table 7

Creep rupture time at 750°C (hr)																	
Stress	The present steel		Comparative steel							Austenite steel (SUS316)							
(MPa)	2	4	9	10	11	12	13	14	15	21	22	23	24	25	26	27	28
88										127	135	145	162	163	170	173	194
80	2173	3550															
69										555	577	615	641	656	680	802	
61																	1371
60					24												
53										1725	2095	2137	2651	2691	2726	2735	2979
50	9033	>16154	97	97		108	92										
47										5547							
41											5384	6564	8302	8873	9266	11767	
40			430	362	326	516	392	239	204								
37										9613	23693						
35					579	970			384								
33												11188	18173	23024	33224		
30	>21023	>20973	1994	1488	1043		1730	1018	667								
26										33279	37610	44459	46417	53844	130478		
25			3621	3079	2333	3882			1307								
20			5713	5050		7884	7115	4209	2819								

EP 2 444 508 A1

[0070] FIG. 6 is a graph representing the temperature dependence of linear expansion coefficient. The graph represents the results of the comparison of the linear expansion coefficients of the steels of the present invention and practical heat-resistant materials.

[0071] The steels 2 and 4 of the present invention were heated from room temperature to 1,000°C at a rate of 1,000°C/h, and the thermal expansion was measured to determine a linear expansion coefficient at each temperature. The linear expansion coefficients of the practical heat-resistant materials are values specified in the boiler and pressure vessel specifications of the American Society of Mechanical Engineers (ASME).

[0072] Table 8 represents the measured data used to create FIG. 6.

Table 8

Temperature °C	Linear expansion coefficient ($\times 10^{-6}$)							
	The present steel		Comparative steel					
	2	4	Ferrite steel		Austenite steel		Ni-based superalloy	
			9Cr-1 Mo	12Cr, 13Cr	18Cr-8Ni	25Cr-20Ni	NCF600	NCF800
50	8.8	10.9	10.8	11.1	15.9	15.2	12.8	14.9
150	9.3	11.1	11.7	11.9	17.7	16.6	13.9	16.4
250	9.9	11.4	12.4	12.2	18.8	17.2	14.9	17.0
350	10.4	11.6	13.0	12.5	19.3	17.9	15.5	17.5
450	11.0	11.8	13.5	12.9	19.8	18.5		18.0
550	11.6	12.0	14.1	13.2	20.7	19.2		18.6
650	12.1	12.2	15.1	13.3	21.6	20.0		19.4
750	12.7	12.4		13.4	21.1	20.9		20.7
850	13.2	12.6						23.7

[0073] It can be seen that the steels 2 and 4 of the present invention have a linear expansion coefficient of 15×10^{-6} or less in a temperature range of from room temperature to 850°C, and that the low thermal expansion properties are comparable to, or better than those of the ferritic steel.

Industrial Applicability

[0074] The present invention realizes a ferritic Cr-steel that has improved heat resistance (creep strength) while maintaining low thermal expansion properties. The ferritic Cr-steel can realize a heat-resistant precision component for mechanical structures, such as turbines, used under high temperatures above 650°C.

Claims

1. A ferritic Cr-steel for a heat-resistant precision component,
characterized in that the ferritic Cr-steel is of a chemical composition that mainly includes, in % by mass,
Cr: 13 to 30%,
Ni: 1×10^{-1} to 2.5%,
C: 1×10^{-3} to $1 \times 10^{-1}\%$, and
N: 1×10^{-3} to $1 \times 10^{-1}\%$,
wherein the ferritic Cr-steel allows for inclusion of an additional component and unavoidable impurities, includes Fe as the remaining part, and forms a ferrite phase.
2. The ferritic Cr-steel for a heat-resistant precision component according to claim 1, wherein Ni is added in an amount that satisfies the relationship $Ni > 10(C + N)$, where Ni, C, and N each represent the amount of each component added (in % by mass), when C is added in $1 \times 10^{-2}\%$ by mass or more and/or Ni is added in $1 \times 10^{-2}\%$ by mass or more.
3. The ferritic Cr-steel for a heat-resistant precision component according to claim 1 or 2, wherein the ferrite phase is 70 volume% or more.
4. The ferritic Cr-steel for a heat-resistant precision component according to claim 1 or 2, wherein the additional

component is one or more of the following in % by mass,

Mo: 5×10^{-1} to 5%,

W: 5×10^{-1} to $1 \times 10\%$,

V: 5×10^{-2} to $4 \times 10^{-1}\%$,

Nb: 1×10^{-2} to $1 \times 10^{-1}\%$,

Co: 1×10^{-1} to $1 \times 10\%$, and

B: 2×10^{-3} to $4 \times 10^{-3}\%$, and

wherein at least one of carbide, nitride, and intermetallic compound is precipitated in crystal grains.

5. The ferritic Cr-steel for a heat-resistant precision component according to claim 4, wherein Mo and W are added in amounts that satisfy the relationship $\text{Mo} + 0.5\text{W} \geq 3.0\%$ by mass, where Mo and W each represent the amount of each component added (in % by mass).

6. A ferritic Cr-steel for use in a heat-resistant precision component and that contains Cr in an amount of from 13% by mass to 30% by mass,
characterized in that the ferritic Cr-steel has a thermal expansion coefficient of 15×10^{-6} or less in a temperature range of from room temperature to 800°C, and a minimum creep rate of $1 \times 10^{-4}/\text{h}$ or less at 700°C under stress of 100 MPa.

7. A process for producing a ferritic Cr-steel for a heat-resistant precision component, the process comprising hot working the ferritic Cr-steel of the chemical composition of claim 1 in a temperature range of 850 to 1,200°C, forming the ferritic Cr-steel into a predetermined shape, subjecting the steel to an annealing treatment in a temperature range of 1,000 to 1,250°C, and cooling the steel to 400°C or less at a cooling rate of 100°C/min or higher.

8. A heat-resistant precision component formed from the ferritic Cr-steel for a heat-resistant precision component of claim 1.

9. The heat-resistant precision component according to claim 8, wherein the heat-resistant precision component is any one of a rotor, a disc, and a blade of a turbine.

10. A process for producing a heat-resistant precision component, the process comprising hot working the ferritic Cr-steel of the chemical composition of claim 1 in a temperature range of 850 to 1,200°C, forming the ferritic Cr-steel into a component shape, subjecting the steel to an annealing treatment in a temperature range of 1,000 to 1,250°C, and cooling the steel to 400°C or less at a cooling rate of 100°C/min or higher.

Fig.1

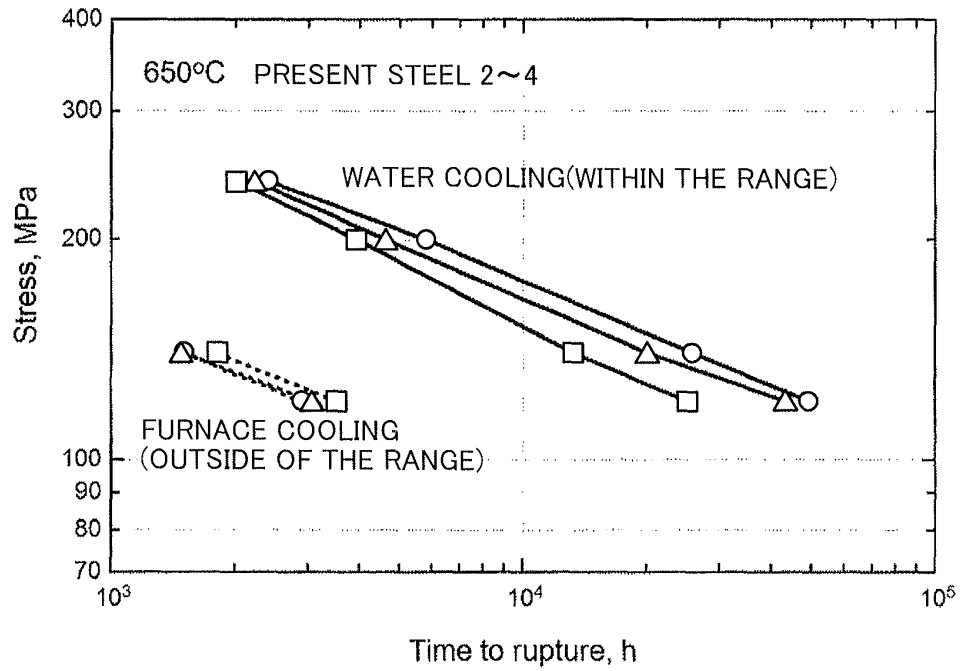


Fig.2

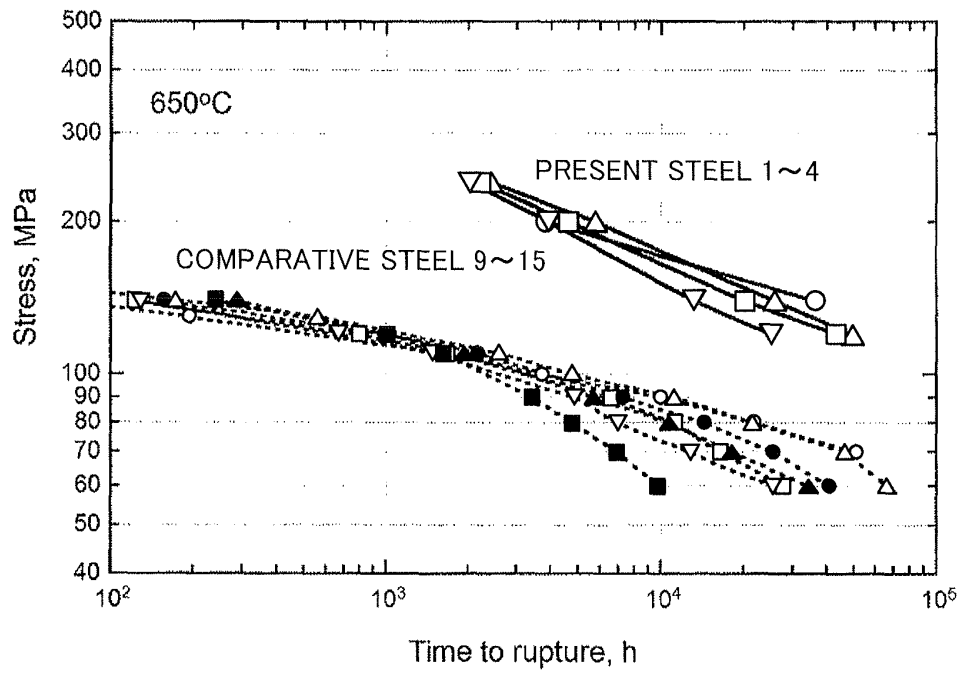


Fig.3

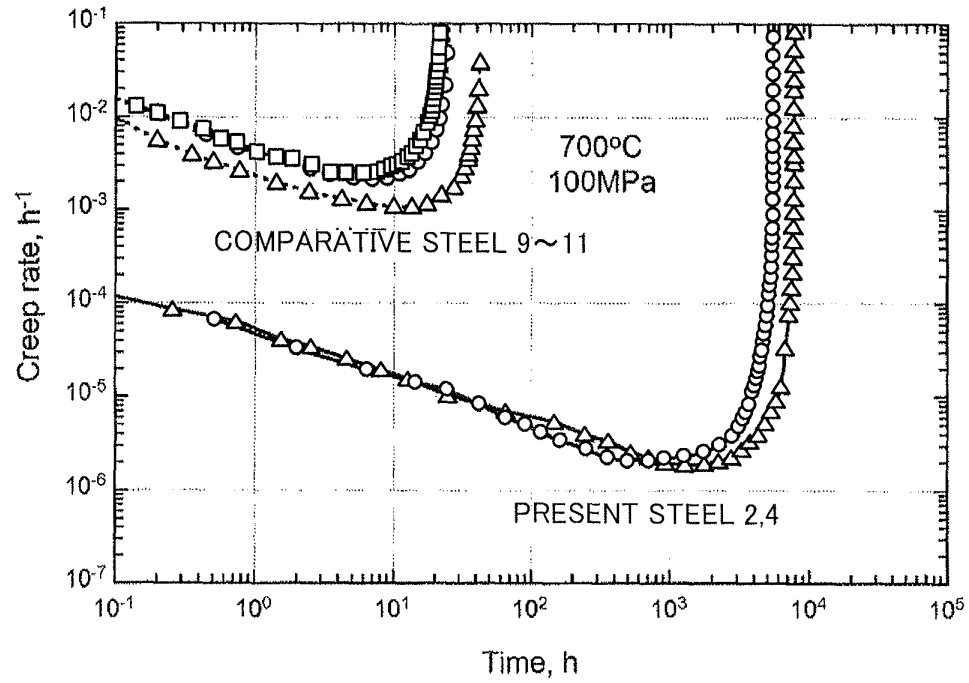


Fig.4

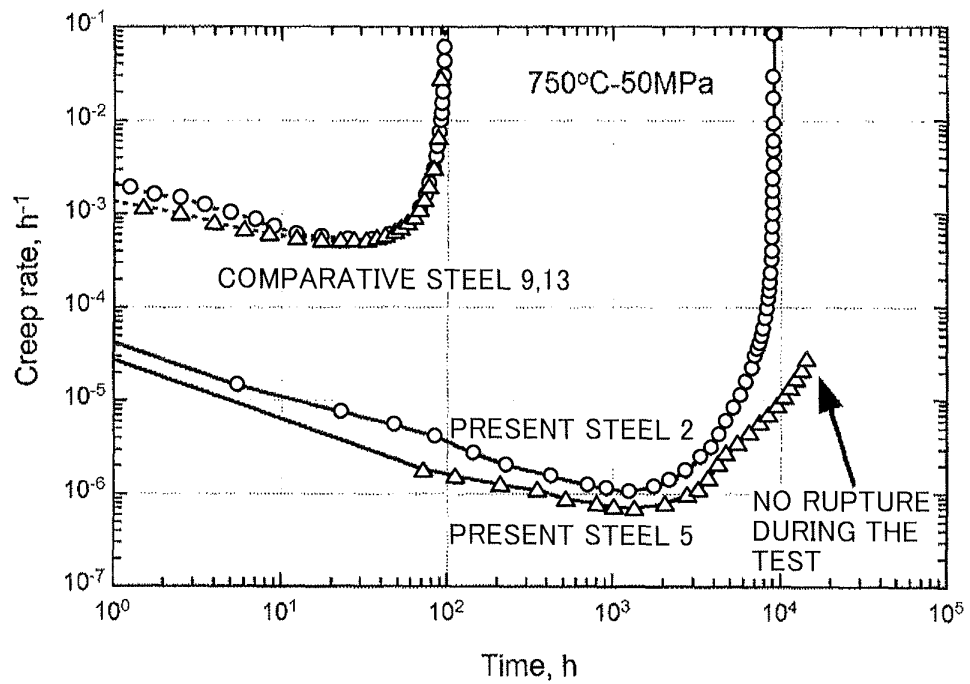


Fig.5

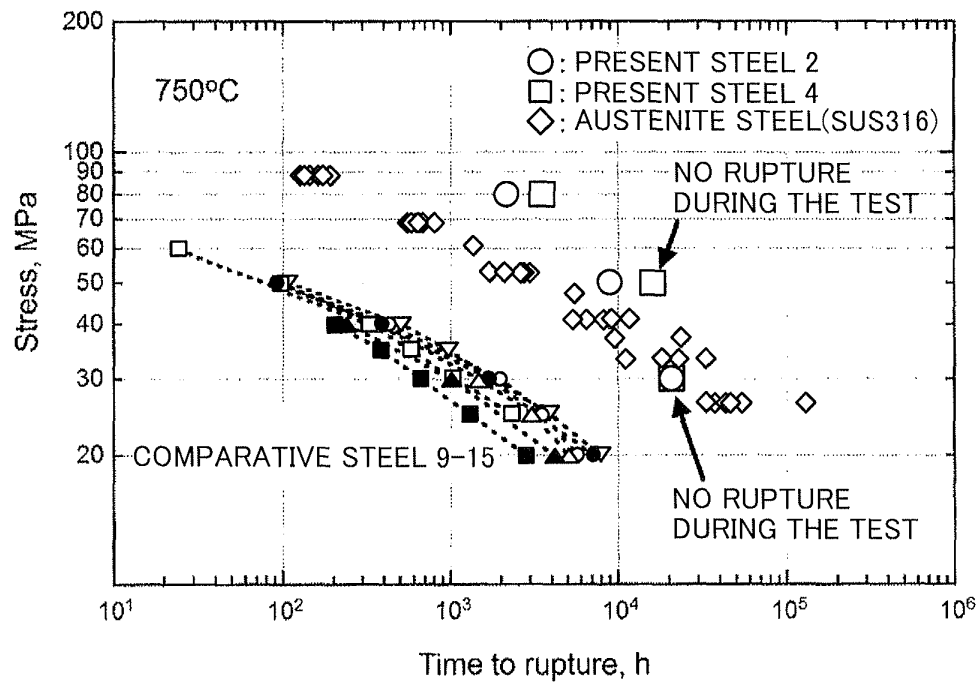
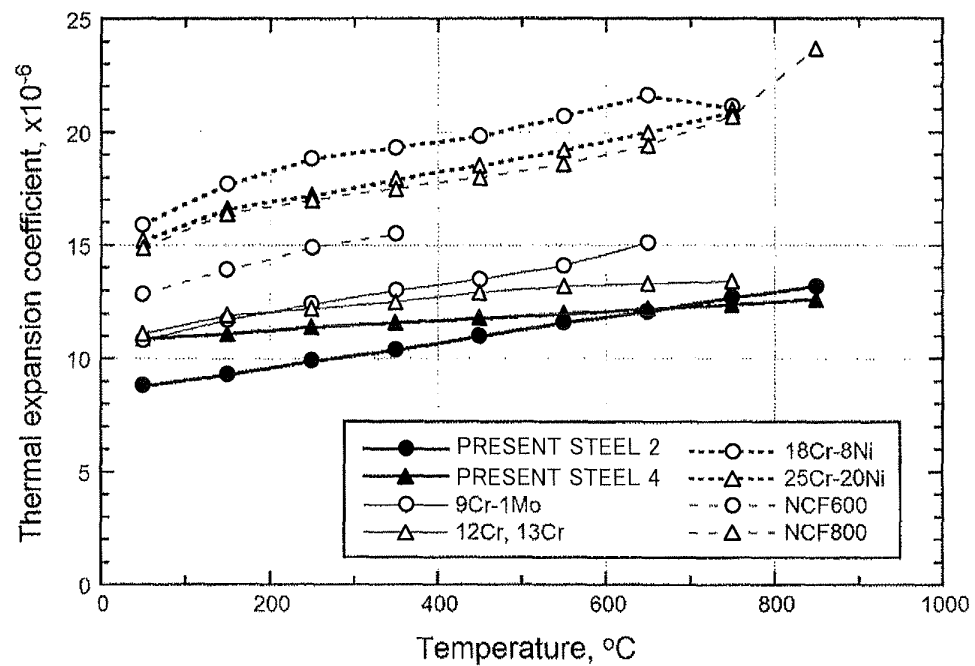


Fig.6



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2010/059453

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C21D6/00(2006.01)i, C21D9/00(2006.01)i, C22C38/54
(2006.01)i, F01D5/28(2006.01)i, F01D25/00(2006.01)i, F02C7/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00, C21D6/00, C21D9/00, C22C38/54, F01D5/28, F01D25/00, F02C7/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2010
Kokai Jitsuyo Shinan Koho	1971-2010	Toroku Jitsuyo Shinan Koho	1994-2010

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2003-253402 A (Independent Administrative Institution National Institute for Materials Science), 10 September 2003 (10.09.2003), claims; paragraphs [0003], [0012] to [0013]; examples; tables 1, 2; fig. 1 (Family: none)	1-10
X	JP 2009-102728 A (JFE Steel Corp.), 14 May 2009 (14.05.2009), claims; paragraphs [0001], [0017], [0049], [0067]; examples (Family: none)	1-10

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
04 August, 2010 (04.08.10)

Date of mailing of the international search report
17 August, 2010 (17.08.10)

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2010/059453

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2004-76154 A (JFE Steel Corp.), 11 March 2004 (11.03.2004), claims; paragraphs [0001], [0038] & EP 1553198 A1	1-5, 8, 9
X	JP 11-236650 A (Kawasaki Steel Corp.), 31 August 1999 (31.08.1999), claims; paragraphs [0023], [0025], [0040]; examples (Family: none)	1-5, 8, 9

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2007332412 A [0007]