

(19)



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(11)

**EP 1 637 615 A1**

(12)

**EUROPEAN PATENT APPLICATION**

(43) Date of publication:

**22.03.2006 Bulletin 2006/12**

(51) Int Cl.:

**C21D 9/36<sup>(2006.01)</sup>  
C22C 38/18<sup>(2006.01)</sup>**

**C22C 38/22<sup>(2006.01)</sup>**

(21) Application number: **05019872.0**

(22) Date of filing: **13.09.2005**

(84) Designated Contracting States:

**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR  
HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI  
SK TR**

Designated Extension States:

**AL BA HR MK YU**

(30) Priority: **16.09.2004 JP 2004269947**

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(54) **Heat-resisting steel, heat treatment method for heat-resisting steel and high-temperature steam turbine rotor**

(57) A heat-resisting steel consisting of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase

structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in percentage by weight are moved into the precipitates after a tempering heat treatment.

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**Description**

## CROSS-REFERENCE TO RELATED APPLICATIONS

5 **[0001]** This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2004-269947 filed on September 16, 2004; the entire contents of which are incorporated herein by reference.

## BACKGROUND

## 10 1. FIELD OF THE INVENTION

**[0002]** The present invention relates to a heat-resisting steel, and more particularly to a heat-resisting steel with outstanding performance as a member for power plant, such as a high-temperature steam turbine rotor material and steam turbine, a heat treatment method for the heat-resisting steel and a high-temperature steam turbine rotor.

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## 2. DESCRIPTION OF THE RELATED ART

**[0003]** As high-temperature part material for the thermal power plant, a low alloy heat-resisting steel represented by 1Cr-1Mo-0.25V steel and a high Cr heat-resisting steel represented by 12Cr-1Mo-VNbN steel are used heavily. But, thermal power plants in these years are being made quickly to have a steam temperature raised higher, and the use of the high Cr heat-resisting steel having outstanding high-temperature properties is increasing.

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**[0004]** Meanwhile, the thermal power plants in these years are required to have high efficiency and economical efficiency. Therefore, it is expected to use as component materials heat-resisting steels which are inexpensive and excellent in properties.

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**[0005]** Parts configuring the center portion of the thermal power plant are formed of large-size materials, which are essentially required to be excellent in productivity and formability into desired shapes. And, they are required to have material properties which are not deteriorated but homogeneous even if formed into large parts. But, for example, a conventional heat-resisting steel having chemical compositions disclosed in Japanese Patent No. 3,334,217 is poor in quenching property when used as large member and can hardly exert desired properties at the center portion of a steel ingot having a large drum diameter. The heat-resisting steel having the chemical compositions disclosed in Japanese Patent No. 3,439,197 has considerable segregation of components when a large steel ingot is cast and can hardly exert uniform material properties in the overall steel ingot. When special dissolution is used to enhance the homogeneity of the steel ingot, the heat-resisting steel has drawbacks including advantages and disadvantages such as poor economical efficiency.

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**[0006]** The conventional heat-resisting steel contains a relatively large amount of ferrite former, such as Cr, Mo and W as reinforcing elements, so that the trend to generate a ferrite phase becomes high. Generally, the ferrite phase generated in a bainite phase is produced by chemical combination of the above-described ferrite former with Fe. Therefore, these elements which are added as the reinforcing elements are locally concentrated in the generated ferrite and have drawbacks that the contents of the elements in the bainitic structure decrease, and especially high-temperature strength is decreased. Besides, when the generated amount of the ferrite phase in the heat-resisting steel increases, impact properties or toughness of the material may be degraded heavily.

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## BRIEF SUMMARY OF THE INVENTION

45 **[0007]** According to an aspect of the present invention, there is provided a heat-resisting steel having a bainite single phase structure which can be used stably in a high temperature steam environment and has outstanding economical efficiency, a heat treatment method for the heat-resisting steel and a high-temperature steam turbine rotor.

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**[0008]** A heat-resisting steel of the present invention consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in percentage by weight are moved into the precipitates after a tempering heat treatment.

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**[0009]** A heat-resisting steel of the present invention consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in percentage by weight are moved into the

precipitates after a tempering heat treatment.

5 [0010] A heat-resisting steel of the present invention consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in percentage by weight are moved into the precipitates after a tempering heat treatment.

10 [0011] According to the above heat-resisting steels, the heat-resisting steels consisting of the bainite single phase structure can be formed by configuring in the ranges of the contents of the individual component elements. Thus, the heat-resisting steels excelling in high-temperature properties, toughness, embrittlement properties and the like and do not have a ferrite phase or the like which considerably decreases the material mechanical properties when the generated amount is increased can be provided. The above-described component elements Ti and/or N may be replaced by Fe and C.

15 [0012] A heat treatment method for a heat-resisting steel of the present invention comprises heating to 980 to 1030°C a steel ingot which consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, cooling such that a cooling speed at the center portion of the steel ingot becomes at least 20°C/h or more, and conducting a tempering treatment.

20 [0013] A heat treatment method for a heat-resisting steel of the present invention comprises heating to 980 to 1030°C a steel ingot which consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, cooling such that a cooling speed at the center portion of the steel ingot becomes at least 20°C/h or more, and conducting a tempering treatment.

25 [0014] A heat treatment method for a heat-resisting steel of the present invention comprises heating to 980 to 1030°C a steel ingot which consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, cooling such that a cooling speed at the center portion of the steel ingot becomes at least 20°C/h or more, and conducting a tempering treatment.

30 [0015] According the above heat treatment methods for the heat-resisting steel, the heat-resisting steel comprising a bainite single phase structure that a ferrite phase is not formed, can be formed even if quenching is effected at a very slow cooling velocity of at least 20°C/h or more at the center portion of the steel ingot without forcedly cooling by, for example, a cooling medium such as water, oil or the like or an air blast.

35 [0016] A high-temperature steam turbine rotor of the present invention comprises a heat-resisting steel which consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in percentage by weight are moved into the precipitates after a tempering heat treatment.

40 [0017] A high-temperature steam turbine rotor of the present invention comprises a heat-resisting steel which consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in percentage by weight are moved into the precipitates after a tempering heat treatment.

45 [0018] A high-temperature steam turbine rotor of the present invention comprises a heat-resisting steel which consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in percentage by weight are moved into the precipitates after a tempering heat treatment.

50 [0019] According to the above high-temperature steam turbine rotors, a high-temperature steam turbine rotor comprising the bainite single phase structure can be formed by configuring in a range of the contents of the individual component elements described above. Thus, there can be provided the high-temperature steam turbine rotor excelling in high-temperature properties, toughness, embrittlement properties and the like which does not have a ferrite phase or the like which considerably degrades the mechanical properties of the materials if the generated amount is increased. The above-described component element Ti and/or N may be replaced by Fe and C. When the high-temperature steam turbine rotors are in steady operation, a total amount of precipitates is secured at 2.8% or more in the vicinity of the

portions of the high-temperature steam turbine rotors exposed to steam at the maximum temperature after the operation for 100,000 hour equivalent. The maximum temperature of steam at the time of the steady operation is approximately 540 to 580°C.

**[0020]** The high-temperature steam turbine rotor is a high-pressure rotor, an intermediate pressure rotor or a high and intermediate pressure rotor. It is a rotor of a steam turbine which is operated with an exhaust temperature of 300°C or more at the final stage outlet of the high-pressure portion of the high pressure rotor or the high and intermediate pressure rotor and an exhaust temperature of 200°C or more at the final stage outlet of the intermediate pressure portion of the intermediate pressure rotor or the high and intermediate pressure rotor. The exhaust steam is introduced into a boiler or a low pressure turbine which is disposed separately.

#### DETAILED DESCRIPTION OF THE INVENTION

**[0021]** One embodiment of the present invention will be described below.

**[0022]** First, the reasons why the ranges of individual components of alloys used in the present invention are limited will be described. The denomination of "%" indicating the components in the following description refers to "% by weight" unless otherwise specified.

(1) C (carbon)

**[0023]** C is an element inevitable as a component element of a variety of carbides contributing to precipitation strengthening and secure quenching property. If its content is less than 0.25 %, the above effects are small. If it exceeds 0.35 %, carbide coarsening is accelerated, and the trend of segregation is enhanced at the time of solidification of a steel ingot. Therefore, it is determined that the C content is in a range of 0.25 to 0.35 %, and more desirably in a range of 0.27 to 0.33 %.

(2) Si (silicon)

**[0024]** Si is useful as a deoxidizing element and improves the resistance to steam oxidation. But, if its content is high, the toughness is decreased and embrittlement is accelerated. Therefore, its content is desired to be as low as possible. If the Si content exceeds 0.15 %, the above favorable properties are degraded considerably. Thus, the Si content is determined to be not more than 0.15 % (excluding 0). And, the Si content is preferably not more than 0.1 %.

(3) Mn (manganese)

**[0025]** Mn is an element useful as a desulfurizing element but, if its content is less than 0.2 %, its desulfurizing effect is not recognized, and if its added amount exceeds 0.8 %, the creep strength is decreased. Therefore, the Mn content is determined to be in a range of 0.2 to 0.8 %, and more preferably in a range of 0.4 to 0.8 %.

(4) Cr (Chromium)

**[0026]** Cr is an element effective for oxidation resistance and corrosion resistance and also inevitable as a component element of carbonitride contributing to enhancement of precipitation. In the heat-resisting steel according to the present invention, Cr is also useful as an element effective in improving the toughness. If the Cr content is less than 1.6 %, the amount of Cr moved into carbonitride after the tempering heat treatment is little, and high-temperature stability of carbonitride cannot be secured. If the Cr content exceeds 1.9 %, resistance to temper softening is decreased, desired normal-temperature strength cannot be secured, and the creep strength is decreased. Therefore, the Cr content is determined to be in a range of 1.6 to 1.9 %.

(5) V (vanadium)

**[0027]** V contributes to the solid-solution strengthening and the formation of fine carbonitride. If the V content is 0.26 % or more, fine precipitates are deposited sufficiently and to inhibit the recovering of the bainitic structure but, if its content exceeds 0.35 %, the toughness is decreased, and coarsening of carbonitride is accelerated. Accordingly, the V content is determined to be in a range of 0.26 to 0.35 %.

(6) W (tungsten)

**[0028]** W contributes to the solid-solution strengthening of the bainitic structure and the precipitation strengthening by

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becoming a component element of carbonitride. Especially, when W and Mo are added together, high-temperature stability of precipitates can be enhanced remarkably. W moves from the bainitic structure into precipitates with time while heating at a high temperature for a long period of time. Therefore, it is necessary to set the W content to 0.9 % or more in order to keep the W content contributing to the solid-solution strengthening high for a long time of period. But, if the W content exceeds 1.4 %, toughness is degraded, ferrite is prone to be generated, and the tendency of segregation of components of a large steel ingot is increased. Therefore, the W content is determined to be in a range of 0.9 to 1.4 %, and more preferably in a range of 0.9 to 1.2 %.

### (7) Mo (molybdenum)

**[0029]** Mo contributes to the solid-solution strengthening and the precipitation strengthening by becoming a component element of carbonitride. Especially, when Mo and W are added together, high-temperature stability of precipitates can be enhanced remarkably. Mo moves from the bainitic structure into precipitates with time while heating at a high temperature for a long period of time. Therefore, it is necessary to set the Mo content to 0.6 % or more in order to keep the Mo content contributing to the solid-solution strengthening high for a long time of period. But, if the Mo content exceeds 0.9 %, toughness is degraded, ferrite is prone to be generated, and the tendency of segregation of components of a large steel ingot is increased. Therefore, the Mo content is determined to be in a range of 0.6 to 0.9 %, and more preferably in a range of 0.7 to 0.9 %.

### (8) N (nitrogen)

**[0030]** N forms nitride or carbonitride and contributes to precipitation strengthening. Besides, N remaining in the bainitic structure also contributes to the solid-solution strengthening but, if the N content is less than 0.001 %, the above effects are not recognized. Meanwhile, if the N content exceeds 0.007 %, coarsening of nitride or carbonitride is accelerated, and the creep strength is decreased. Therefore, the N content is determined to be in a range of 0.001 to 0.007 %. For the formation of carbonitride in the heat-resisting steel of the present invention, N can be substituted by increasing the C content within the range of the C content. Fe may be used instead of N.

### (9) Ti (titanium)

**[0031]** Ti is useful as a deoxidizing element. If the Ti content is less than 0.01 %, it exerts a deoxidizing effect, and the remaining Ti is formed into solid solution. But, if the Ti content exceeds 0.01 %, a generated amount of non-solid solution coarse Ti carbonitride increases, causing a decrease in toughness or weakening of the notch. Therefore, the Ti content is determined to be less than 0.01 % (excluding 0). Inclusion of Ti in the above content allows decreasing the amount of O (oxygen) in the steel ingot by the deoxidizing effect, and oxide can also be prevented from being produced at the time of producing the steel ingot. Ti can be substituted by increasing the C content within the range of the C content. And, Fe may be used instead of Ti.

### (10) Ni (nickel)

**[0032]** Ni improves quenching property and toughness and has an effect to suppress ferrite from being generated. This effect is observed when the Ni content is 0.35 or more. But, if the Ni content exceeds 0.6%, the creep strength is decreased. Therefore, the Ni content is determined to be in a range of 0.3 to 0.6 %.

**[0033]** It is desirable to reduce as much as possible impurities which are mixed incidentally at the time of adding the above-described components and the main component Fe. Inevitable impurities in the heat-resisting steel of the present invention include P (phosphorus), S (sulfur), Cu (copper), Al (aluminum), As (arsenic), Sn (tin), Sb (antimony) and O (oxygen). These impurities induce embrittlement when the heat-resisting steel is heated at a high temperature for a long time of period. With respect to the elements of those inevitable impurities, it is desired to reduce their contents to zero as much as possible, specifically P of less than 0.015 %, S of less than 0.005 %, Cu of less than 0.1 %, Al of less than 0.01 %, As of less than 0.005 %, Sn of 0.005 %, Sb of less than 0.005 %, and oxygen of less than 20 ppm.

**[0034]** Then, the reasons of limiting a total of Mo and W/2 to 1.3 to 1.4 will be described.

**[0035]** In the heat-resisting steel of the present invention, W and Mo each have the effects as described in (6) and (7) above. When they are added together, the creep strength is improved better than when added separately, while the tendency of segregation of components of light elements increases considerably at the time of producing a large steel ingot. It is necessary to limit the amount of W and Mo added together in order to exert a desired creep strength and to avoid segregation. To do so, it is generally desirable to use an index called Mo equivalent (a total content of Mo and W/2 (% by weight)). For the heat-resisting steel of the present invention, when the Mo equivalent is less than 1.3, the creep strength is decreased, and if the Mo equivalent exceeds 1.4, segregation of components becomes considerable at the

time of production of a large steel ingot. Therefore, the Mo equivalent (a total content of Mo and W/2 (% by weight)) is determined to be 1.3 to 1.4.

**[0036]** Then, the reason why Fe of 1.0 or more, Cr of 0.8 to 0.9, Mo of 0.4 to 0.5, W of 0.3 to 0.5 and V of 0.2 or more in % by weight are contained in the precipitates after the tempering heat treatment of heat-resisting steel in the added amount of elements in the above range, and a total amount of the precipitates is secured to be 3.5 or more will be described.

**[0037]** The heat-resisting steel of the present invention is reinforced by the solid-solution strengthening of the bainitic structure and the precipitation of carbonitride. Carbonitride is precipitated intentionally by the tempering heat treatment, and the precipitates in the heat-resisting steel of the present invention are four kinds of M, VC, R type, M, RC type, M, QC type and MC type. M indicates a metal element. M in the M, VC, R type and M, RC type is mainly Fe and Cr, and Mo, W and the like might be contained additionally. M in the M, QC type is mainly Mo and W, and V might be contained additionally. M in the MC type is mainly V, and Mo and W might be contained additionally.

**[0038]** The reasons why the above-described Fe, Cr, Mo, W and V are limited to the individual component ranges will be described. The denomination of "%" indicating compositions in the following description refers to "% by weight" unless otherwise specified.

**[0039]** The amount of precipitates was measured and identified as follows. A test sample was placed in a mixed liquid of methanol, acetylacetone and tetramethyl ammonium chloride and a bainitic structure was dissolved by electrolysis. After filtering, the resultant residue was washed and measured for its weight. And the value determined by dividing by the weights before and after the dissolving was used. Besides, the recovered residue was determined for the kinds of precipitates by X-ray analysis or the like.

(11) Fe (iron)

**[0040]** Fe in the precipitate is mainly a component element of M, VC, R type and M, RC type precipitates and contributes to precipitation strengthening. If the amount of Fe moved into the precipitate after the tempering heat treatment is less than 1.0 %, the precipitated amount is small and the precipitation strengthening action does not work sufficiently. To exert the creep strength, it is effective to use the transformation with time after depositing as M,RC type precipitates after the tempering heat treatment but, if the moved amount of Fe is less than 1.0 %, the precipitated amount of the M, RC type precipitate is small, so that the increase in creep strength cannot be expected by this method. Therefore, the Fe content in the precipitate after the tempering heat treatment was determined to be 1.0 % or more.

(12) Cr (chromium)

**[0041]** Cr in the precipitates is mainly a component element of M, VC, R type and M, RC type precipitates and contributes to precipitation strengthening. Cr substitutes for part of Fe in the precipitates, so that it also has an action to enhance the stability of the precipitates. If the amount of Cr moved into the precipitates after the tempering heat treatment is less than 0.8 %, the precipitated amount is small, and the precipitation strengthening action does not work sufficiently. Meanwhile, if the amount of Cr moved into the precipitates after the tempering heat treatment exceeds 0.9 %, disappearance of Fe, RC type precipitates is induced during the tempering heat treatment, and the time lapse effect described in (11) above cannot be exerted. Therefore, the Cr content in the precipitates after the tempering heat treatment was determined to be in a range of 0.8 to 0.9 %.

(13) W (tungsten)

**[0042]** W in the precipitates is mainly a component element of the M, QC type precipitate and contributes to precipitation strengthening. W substitutes for part of the M, VC, R type, M, RC type and MC type precipitates, so that it enhances the high-temperature stability of the precipitates considerably. If the amount of W moved into the precipitates after the tempering heat treatment is less than 0.3 %, the stability of the precipitates is low and a desired creep strength cannot be exerted. Meanwhile, if the amount of W moved into the precipitates after the tempering heat treatment exceeds 0.5 %, the solid solution amount of W in the bainitic structure decreases, and the solid-solution strengthening amount at a high temperature decreases. Therefore, the W content in the precipitates after the tempering heat treatment was determined to be in a range of 0.3 to 0.5 %.

(14) Mo (Molybdenum)

**[0043]** Mo in the precipitates is mainly a component element of M, QC type precipitate and contributes to precipitation strengthening. Mo substitutes for part of the M, VC, R type, M, RC type and MC type precipitates and enhances the high-temperature stability of the precipitates considerably. If the amount of Mo moved into the precipitates after the tempering heat treatment is less than 0.4 %, the stability of the precipitates is low, and a desired creep strength cannot

be exerted. Meanwhile, if the amount of Mo moved into the precipitates after the tempering heat treatment exceeds 0.5 %, the solid solution amount of Mo in the bainitic structure decreases, and the solid-solution strengthening amount at a high temperature decreases. Therefore, the Mo content in the precipitates after the tempering heat treatment was determined to be in a range of 0.4 to 0.5 %.

(15) V (vanadium)

**[0044]** V in the precipitates is mainly a component element of fine MC type precipitate and contributes to precipitation strengthening. V substitutes for part of the M, VC, R type, M, RC type and M, QC type precipitates and enhances the high-temperature stability of the precipitates considerably. If the amount of V moved into the precipitates after the tempering heat treatment is less than 0.2 %, the precipitated amount of the MC type precipitate decreases, and the stability of the other precipitates becomes low. Therefore, the V content in the precipitates after the tempering heat treatment was determined to be 0.2 % or more.

**[0045]** For fine and homogeneous dispersion of the precipitates mainly consisting of five elements of the above-described (11) to (15) and C, N and the like by the tempering heat treatment, the total amount of the precipitates is required to be 3.5 % or more. If the total amount is less than 3.5 %, strength characteristics and high-temperature stability of the precipitates are decreased as described in the above (11) through (15). Therefore, the total content of the precipitates after the tempering heat treatment was determined to be 3.5 % or more.

**[0046]** Then, the reason why it is desirable that the total amount (3.5 %) of the precipitates of the above-described (11) through (15), after the tempering heat treatment of a high-temperature steam turbine rotor formed of the heat-resisting steel which is comprised of the component elements in the range of the above-described (1) through (10), is secured to be 2.8 % or more even if decreased from the total amount of the precipitates after the tempering heat treatment after the operation for 100,000 hour equivalent in the vicinity of the portion exposed to the steam at the maximum temperature at the time of a steady operation.

**[0047]** The heat-resisting steel configuring the high-temperature steam turbine rotor of the present invention is different from the ordinary heat-resisting steel, and the solid solution amount and the precipitated amount of the carbonitride change with time during the operation, causing exertion of outstanding high-temperature properties. Mo and W which are in the supersaturated solid solution state in the heat-resisting steel mainly move into the M, QC type precipitate and the MC type precipitate with time, to enhance their high-temperature stability, the M, RC type precipitate having Fe as a main component element transforms into M, VC, R type precipitate which is more stable than when having Cr as the main component element with time to keep the creep strength. Especially, the latter involves dissolution of Fe in the M, RC type precipitate deposited in a large amount by the tempering heat treatment, so that the total amount of precipitates decreases in comparison with that after the tempering heat treatment. The remaining M, RC type precipitate has an effect of keeping the creep strength but, if the total amount of precipitates is less than 2.8 %, the M, RC type precipitate is eliminated completely, and the precipitation strengthening action is decreased rapidly. Therefore, the total amount of precipitates after the operation for 100,000 hour equivalent was determined to be 2.8 % or more.

**[0048]** Precipitates deposited in the heat-resisting steel configuring the high-temperature steam turbine rotor are different in precipitated amount depending on their types, and their precipitated amount are variable with time depending on the operation of the high-temperature steam turbine rotor, but no new type of precipitate is deposited when operating. And the maximum temperature of steam during a steady operation is in a range of approximately 540 to 580°C.

**[0049]** Then, the reason why the grain diameter of prior austenite is preferably 100 μm or less in average will be described.

**[0050]** The prior austenite grain diameter has no small effect on the individual mechanical properties. If it exceeds 100 μm, ductility is lowered, crack at grain boundary is caused easily, notch creep strength and toughness are decreased. Therefore, the prior austenite grain diameter was determined to be 100 μm or less in average.

**[0051]** The grain diameter is finally determined depending on the heating temperature at the time of quenching. For the heat-resisting steel of the present invention, a heating temperature of 980 to 1030°C is desirable. If the heating temperature is less than 980°C, a sufficient quenching effect cannot be obtained, and desired mechanical properties cannot be exerted. Meanwhile, if the heating temperature exceeds 1030°C, the grains become coarse considerably. The property is decreased considerably with the above-described coarsening of the grains.

**[0052]** The heat-resisting steel and high-temperature steam turbine rotor of the present invention contain the elements of the above-described (1) through (10) in a prescribed range, the Mo equivalent is in a prescribed range, and the prior austenite grain diameter is 100 μm or less in average. And, the elements described in the above (11) and (12) are contained in a prescribed range within the precipitates. After the operation for 100,000 hour equivalent in the vicinity of the portion of the high-temperature steam turbine rotor exposed to steam at the maximum temperature at the time of a steady operation, the total amount of precipitates can be secured at a prescribed value or more, and desired mechanical properties can be exerted accordingly.

**[0053]** Like the heat-resisting steel of the present invention, where ferrite former such as Cr, Mo, W, V and the like

are contained, ferrite may be generated in metal structure depending on the added amounts of the individual elements. These elements are concentrated in ferrite of a low alloy steel, and the effects of the above-described elements cannot be exerted sufficiently. Therefore, the heat-resisting steel of the present invention is determined to have the added range of the individual added elements ((1) through (10)) so as to have a bainite single phase structure.

**[0054]** The ferrite phase may be generated depending on the heating temperature at the time of production or the cooling conditions after the heating. Especially, where heating and cooling are repeated in the production process and the steam turbine rotor material has a large material size, a ferrite phase is generated depending on, for example, a cooling speed at the time of quenching. In other words, the ferrite phase has a feature that it is generated when exposed to a prescribed temperature range for a prescribed time of period. For example, if the cooling speed at the time of quenching is low, it passes through the generation region in the cooling step. As a result, the structure with the ferrite phase generated in the bainite structure is obtained, and the properties are degraded.

**[0055]** Even when carbonitride is deposited in ferrite, properties are degraded in comparison with the bainite single phase structure, and the component concentration and structure are unavoidable from becoming non-uniform. Therefore, in order to avoid the generation region at the time of quenching, the adjustment of the cooling speed and obtaining the bainite single phase structure are focused in the production of heat-resisting steel.

**[0056]** But, the heat-resisting steel and high-temperature steam turbine rotor having the component range according to the present invention can be provided with a bainite single phase structure having good mechanical properties at a high temperature without limiting the cooling speed. Besides, according to the heat-resisting steel and high-temperature steam turbine rotor of the present invention, a stable operation can be conducted in a high-temperature steam environment, and it is good in economical efficiency.

**[0057]** Embodiments of the present invention will be described below.

(First Embodiment)

**[0058]** It will be described that the heat-resisting steel according to one embodiment of the present invention has excellent properties. The sample steels in the first embodiment were produced by dissolving about 30 kg of material having the chemical composition range of the present invention, casting it, hot forging the cast ingot, performing annealing, normalizing and quenching, and tempering. The quenching was performed at 980 to 1030°C on the cast ingot after the normalizing such that the cooling speed approximately in the center of the cast ingot became 20 to 80°C/h.

**[0059]** Table 1 shows chemical compositions of the produced sample steels. Among the sample steels shown in Table 1, steel type P1 through steel type P 14 are heat-resisting steels having compositions in the range according to the present invention. Meanwhile, steel type C1 through steel type C6 are heat-resisting steels having compositions which are not in the chemical compositions in the range according to the present invention and are comparative examples. Table 1 also shows the remaining amounts of oxygen of the individual steel types. The numeric values in Table 1 are in % by weight.

**[0060]** As shown in Table 1, the remaining amount of oxygen in the sample steels containing Ti is at most 10 ppm. This value is lower than the remaining amount of oxygen in the sample steels not containing Ti, indicating that the deoxidization by addition of Ti is effectively working. The steel type C2 has a deoxidizing effect but generates Ti carbonitride in a state of non-solid solution.

**[0061]** The steel types shown in Table 1 are adjusted to have the 0.02% proof stress of approximately 660 to 690 MPa at normal temperature suitable for the turbine rotor as shown in Table 2.

**[0062]** For the individual steel types, notched test pieces for Charpy impact test according to JIS Z 2202 having a thickness of 2 mm and V notch were prepared, and a Charpy impact test with these test pieces was conducted. The test results are shown in Table 2. Table 2 also shows the measured results of rupture time of a creep rupture test under conditions of 600°C and 196 MPa.

**[0063]** The steel types P1 through P14 of the embodiment in the chemical composition range of the present invention had 50 to 55J impact absorption energy at 20°C. Meanwhile, the steel types C1 to C6 of the comparative example had impact absorption energy of at most 40J at 20°C, and the impact absorption energy was generally lower than in the embodiment.

**[0064]** Rupture time in the creep rupture test conducted on the individual steels under conditions of 600°C and 196 MPa was about 1850 hours at shortest for the steel types P1 through P14 of the embodiment. Meanwhile, creep rupture time of the steel types C1 through C6 of the comparative example was 800 to 1530 hours.

**[0065]** Among the steel types of the comparative example, the steel type C1, steel type C3 and steel type C5 which had a relatively long rupture time had impact absorption energy at 20°C considerably lower than those of the individual steel types of the embodiment. When Mo equivalent (the total content of Mo and W/2 (% by weight)) is less than 1.3 as the steel type C4 has and when Mo equivalent exceeds 1.4 as the steel type C5 has, the creep rupture time is short clearly. In addition, even if the Mo equivalent is in a range of 1.3 to 1.4, the creep rupture time was short and the impact absorption energy was low if the added amounts of the other elements are not within the chemical composition range

of the present invention.

**[0066]** It was found from the above that the heat-resisting steels of the embodiment, when adjusted to the same 0.02 % proof stress at normal temperature, had excellent values of both the impact absorption energy and the creep rupture time in comparison with the heat-resisting steels of the comparative example having the amounts of added elements not within the composition range of the present invention. And, it was also clarified that the addition of Ti decreases the amount of oxygen remaining in the steel ingot.

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[Table 1]

Steel type	C	Si	Mn	Ni	Cr	V	W	Mo	Ti	N	O (ppm)	Fe	Mo+W/2
E	0.27	0.05	0.31	0.35	1.78	0.28	1.16	0.75	0.007	0.006	9	Balance	1.330
X	0.26	0.06	0.29	0.35	1.62	0.29	1.38	0.66	0.002	0.006	8	Balance	1.350
A	0.27	0.05	0.33	0.38	1.85	0.35	0.91	0.86	0.008	0.005	9	Balance	1.315
M	0.31	0.09	0.59	0.42	1.72	0.31	1.01	0.88	0.003	0.005	9	Balance	1.385
P	0.32	0.12	0.55	0.32	1.67	0.30	1.28	0.73	0.002	0.005	10	Balance	1.370
P	0.31	0.05	0.61	0.31	1.88	0.34	0.97	0.89	0.003	-	8	Balance	1.375
L	0.34	0.04	0.78	0.48	1.82	0.34	1.37	0.64	0.001	-	7	Balance	1.325
E	0.31	0.07	0.72	0.54	1.70	0.31	1.22	0.71	0.002	0.004	9	Balance	1.320
P	0.30	0.05	0.21	0.36	1.75	0.26	1.21	0.73	0.005	0.006	10	Balance	1.335
P	0.31	0.06	0.55	0.52	1.85	0.35	1.36	0.63	-	0.007	15	Balance	1.310
P	0.29	0.06	0.59	0.37	1.72	0.32	1.39	0.62	-	0.003	14	Balance	1.315
P	0.29	0.07	0.60	0.31	1.61	0.34	1.09	0.82	-	0.005	16	Balance	1.365
P	0.33	0.09	0.45	0.42	1.74	0.29	0.92	0.85	-	-	12	Balance	1.310
P	0.33	0.06	0.52	0.39	1.65	0.27	1.31	0.74	-	-	14	Balance	1.395
C1	0.24	0.05	0.68	0.44	1.83	0.27	0.67	1.02	-	0.004	15	Balance	1.355
C2	0.28	0.17	0.51	0.53	1.79	0.28	1.52	0.55	0.009	-	9	Balance	1.310
C3	0.30	0.05	0.59	0.35	1.15	0.28	-	1.33	-	0.003	16	Balance	1.330
C4	0.05	0.19	0.49	0.02	2.23	0.23	1.58	0.12	-	0.008	14	Balance	0.910
C5	0.25	0.07	0.82	0.84	1.25	0.25	0.42	1.25	-	-	13	Balance	1.460
C6	0.36	0.05	0.17	0.25	1.85	0.33	1.36	0.65	-	0.002	16	Balance	1.330

\*CE: Comparative Example

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[Table 2]

	Steel Type	0.02% proof stress at room temperature (MPa)	600°C-196 MPa creep rupture time (h)	Absorbed energy at 20°C (J)
Example	P1	675	2178	55
	P2	670	1942	52
	P3	690	2054	54
	P4	665	1905	53
	P5	670	2008	50
	P6	685	2265	50
	P7	670	1895	55
	P8	673	1854	50
	P9	669	2058	50
	P10	680	1980	52
	P11	668	2057	50
	P12	670	2237	50
	P13	690	1878	52
	P14	680	1968	50
Comparative Example	C1	664	1527	12
	C2	674	927	18
	C3	665	1347	12
	C4	658	812	40
	C5	660	1280	25
	C6	668	983	31

(Second Embodiment)

**[0067]** It will be described that the heat-resisting steels having the chemical composition range of the present invention are desirably adjusted to a state of securing a prescribed precipitated amount when they are subjected to the tempering heat treatment.

**[0068]** In the second embodiment, the steel type P1, the steel type P6, the steel type P11 and the steel type P14 shown in Table 1 were quenched from 990°C, such that the cooling speed approximately at the center of the sample steels becomes 20 to 80°C/h, and subjected to the tempering heat treatment at 630 to 730°C.

**[0069]** Table 3 shows the contents (% by weight) of Fe, Cr, Mo, W and V among the elements contained in the precipitates after the tempering heat treatment of the sample steels and the total amount (% by weight) of the precipitates. Table 3 also shows the measures results of rupture time of the creep rupture test conducted on the sample steels under conditions of 600°C and 196 MPa.

**[0070]** It is seen from the measured results shown in Table 3 that when the contents of the individual elements contained in the precipitates after the tempering heat treatment of the individual steel types shown as the comparative example are not within the above-described range of the contents of the elements contained in the precipitates of the present invention and when the total amount of the precipitates is smaller than the range (3.5% by weight or more) of the total amount of the precipitates of the present invention, the creep rupture time becomes considerably short.

**[0071]** Meanwhile, it is seen that the heat-resisting steels (embodiment) which satisfy the contents of the elements contained in the precipitates of the present invention and have the total amount not smaller than the total amount (3.5 % by weight or more) of the precipitates of the present invention exert excellent creep rupture property. Among the individual steel types, the heat-resisting steels shown in the embodiment can secure not only the creep rupture property but also sufficient impact absorption energy as it is presumable from the results of the steel type P1, the steel type P6,

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the steel type P11 and the steel type P14 in Table 2.

[Table 3]

Steel type		Contents in precipitate after tempering heat treatment (Wt%)					Total amount of precipitates (Wt%)	600°C-196 MPa creep rupture time (h)
		Fe	Cr	Mo	W	V		
P1	E	1.27	0.85	0.46	0.36	0.26	3.77	2065
	E	1.54	0.85	0.42	0.42	0.26	3.89	2178
	CE	0.95	0.83	0.34	0.28	0.24	3.34	1684
P6	E	1.67	0.86	0.45	0.41	0.29	4.08	2084
	E	1.90	0.86	0.47	0.47	0.29	4.16	2265
	CE	0.92	0.77	0.37	0.28	0.23	3.42	1551
P11	E	1.85	0.82	0.44	0.45	0.27	4.05	2057
	CE	1.43	0.92	0.52	0.53	0.27	3.96	1478
P14	E	1.95	0.82	0.43	0.39	0.25	3.65	1968
	E	1.29	0.84	0.55	0.51	0.24	4.23	1069
	CE	0.63	0.57	0.24	0.21	0.18	2.05	976

E=Example; CE=Comparative Example

(Third Embodiment)

**[0072]** It will be described that when the heat-resisting steels in the chemical composition range of the present invention are subjected to the tempering heat treatment, they are adjusted to a state securing a prescribed precipitated amount, and the total amount of the precipitates is desirably secured at 2.8 % by weight or more in the vicinity of the portion exposed to a high-temperature steam at a prescribed temperature for 100,000 hour equivalent.

**[0073]** In the third embodiment, heat-resisting steels of the steel type P2, steel type P7, steel type P10 and steel type P13 shown in Table 1 that the total amount of the precipitates after the tempering heat treatment satisfies the content range of the elements contained in the precipitates of the present invention, and the total amount of the precipitates is not less than the total amount (3.5 % by weight or more) or more of the precipitates of the present invention were determined as sample steels. And, the sample steels were heated at a temperature in a range of 550 to 600°C for 100,000 hour equivalent.

**[0074]** Table 4 shows the measured results of the total amount of the precipitates after the tempering heat treatment, the total amount of the precipitates after heating for 100,000 hour equivalent and the measured results of the rupture time by the creep rupture test under conditions of 600°C and 196 MPa.

**[0075]** It is seen from the measured results shown in Table 4 that when the total amount of the precipitates after heating exceeds 2.8 % by weight (embodiment column), the creep rupture time is 1500 hours or more, securing at least 80 % or more of rupture time with respect to the creep rupture time of the steel types P1 through P14 shown in Table 2. Meanwhile, when the total amount of the precipitates after heating is less than 2.8 % (comparative example column), the creep rupture time is about 700 to 825 hours, and the rupture time was about 40 % of the creep rupture time of the steel types P1 through P14 shown in Table 2.

**[0076]** It is seen from the above that when the heat-resisting steels which are in the chemical composition range of the present invention are subjected to the tempering heat treatment, the elements described in (11) to (12) are contained in a prescribed range in the precipitates, and when heating is conducted at, for example, a high temperature of 550 to 600°C for 100,000 hour equivalent and if the total amount of the precipitates after that becomes 2.8 % by weight or more, a considerably long creep rupture time can be obtained in comparison with the comparative example that does not reach that total amount of the precipitates.

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[Table 4]

Steel type	Total amount of precipitates after tempering heat treatment (Wt%)	Example		Comparative Example	
		Total amount of precipitates after heating (Wt%)	600°C-196 MPa creep rupture time (h)	Total amount of precipitates after heating (Wt%)	600°C-196 MPa creep rupture time (h)
P2	3.87	2.93	1624	2.76	825
P7	3.71	2.86	1520	2.61	811
P10	4.02	3.22	1648	2.35	703
P13	4.18	3.71	1585	2.73	796

(Fourth Embodiment)

[0077] It will be described that the heat-resisting steel in the chemical composition range of the present invention is suitable for the production of a steel ingot which has small segregation of component concentration and is homogeneous.

[0078] According to the fourth embodiment, it was assumed that 60 tons or more of steel ingots having the chemical compositions of the steel type P6, the steel type P12, the steel type C2 and the steel type C6 shown in Table 1 were produced, and numerical simulation was performed on the tendency of segregation.

[0079] According to the numerical simulation, the cast ingot produced by using a mold having a value about 1.5 obtained by dividing the height of the mold at the time of casting by the diameter of the mold was analyzed for component concentration in a height direction at the center portion of the cast ingot after solidification.

[0080] Table 5 shows the analyzed results of the component concentration of C which is the lightest element and W which is the heaviest element among those configuring the above-described steel type. The values in Table 5 are values obtained by dividing the component concentration of the individual portions of the steel ingot by the component concentration of a molten metal. And, the distance 100 % from the bottom of the steel ingot indicates the top end of the steel ingot.

[0081] It is seen from the analyzed results shown in Table 5 that the concentration ratio of C which was the lightest element in the steel type P6 and the steel type P12 was in a range of 0.93 to 1.15, and that of W which was the heaviest element was about 1.0. Meanwhile, it is seen that the concentration ratio of C in the steel type C2 and the steel type C6 becomes high toward the end portion of the steel ingot and considerable segregation of components has occurred.

[0082] It is seen from the above results that the chemical composition range of the present invention is suitable for production of a steel ingot which has a small segregation of component concentration and is homogeneous.

[Table 5]

Steel Type	Element	Distance from steel ingot bottom				
		5%	30%	50%	80%	100%
P6	C	0.94	0.97	1.00	1.00	1.12
	W	1.03	1.02	1.02	1.02	1.03
P12	C	0.93	0.97	1.03	1.09	1.15
	W	1.02	1.04	1.00	1.03	1.04
C2	C	0.93	0.98	1.03	1.26	1.36
	W	1.07	1.04	1.03	1.03	1.04
C6	C	0.91	0.94	1.15	1.21	1.35
	W	1.08	1.08	1.07	1.05	1.05

(Fifth Embodiment)

[0083] It will be described why it is desirable to adjust the prior austenite grain diameter of the heat-resisting steel having the chemical composition range of the present invention to 100 μm or less in average.

[0084] According to the fifth embodiment, the steel type P3, the steel type P7, the steel type P12 and the steel type P13 shown in Table 1 were used as sample steels. The grain diameters of the sample steels were adjusted by hot working, then they were adjusted to the 0.02 % proof stress of about 660 to 690 MPa at normal temperature suitable

for the turbine rotor.

**[0085]** The sample steels were measured for the grain diameter by the test method described in JIS G 0551. And, reduction of area at 300°C was measured according to the method of tensile test described in JIS Z 2241. In addition, it was measured whether the notch creep rupture strength by the creep rupture test at 300°C was enhanced or reduced in comparison with a lubricating material.

**[0086]** Table 6 shows the results of the above-described measurements.

**[0087]** It is seen from the measured results shown in Table 6 that if the prior austenite grain diameter is not more than 100 μm (Embodiment), 50 % or more of tensile reduction of area and notch strengthening can be exerted but, if the prior austenite grain diameter exceeds 100 μm (Comparative Example), the tensile reduction of area is decreased sharply, and the notch is weakened.

**[0088]** It is seen from the above that excellent tensile characteristic and creep rupture property can be exerted by adjusting the heat-resisting steel within the chemical composition range of the present invention to a prescribed deposited state and the grain diameter to 100 μm or less.

[Table 6]

Steel type		Grain diameter (μm)	Tensile reduction of area at 300°C	Notch creep
P3	E	60	55	Notch strengthening
	E	95	50	Notch strengthening
	CE	110	28	Notch weakening
P7	E	55	57	Notch strengthening
	E	80	52	Notch strengthening
	CE	110	28	Notch weakening
P12	E	70	57	Notch strengthening
	CE	105	26	Notch weakening
P13	E	85	55	Notch strengthening
	CE	120	25	Notch weakening
E=Example, CE=Comparative Example				

**[0089]** The present invention is not limited to the above-described embodiments, and various modifications and alterations may be made within the technical scope of the present invention. And the modified or altered embodiments are also included in the technical scope of the present invention.

**Claims**

1. A heat-resisting steel consisting of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in percentage by weight are moved into the precipitates after a tempering heat treatment.
2. A heat-resisting steel according to claim 1, wherein the Ti and/or N is replaced by Fe and C.
3. A heat-resisting steel according to claim 1 or 2, wherein the heat-resisting steel has a tempered bainite single phase structure having a prior austenite grain diameter of 100 μm or less in average, and the precipitate types are not changed even if M, RC type precipitates, M, VC, R type precipitates, M, QC type precipitates and MC type precipitates are deposited in the bainite single phase structure and exposed to high-temperature steam of a prescribed temperature for 100,000 hour equivalent.
4. A heat-resisting steel consisting of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 1.3 to 1.4

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of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in percentage by weight are moved into the precipitates after a tempering heat treatment.

5 5. A heat-resisting steel according to claim 4, wherein the Ti and/or N is replaced by Fe and C.

6. A heat-resisting steel according to claim 4 or 5,  
10 wherein the heat-resisting steel has a tempered bainite single phase structure having a prior austenite grain diameter of 100  $\mu\text{m}$  or less in average, and the precipitate types are not changed even if M, RC type precipitates, M, VC, R type precipitates, M, QC type precipitates and MC type precipitates are deposited in the bainite single phase structure and exposed to high-temperature steam of a prescribed temperature for 100,000 hour equivalent.

7. A heat-resisting steel consisting of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn,  
15 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in percentage by weight are moved into the precipitates after a tempering heat treatment.

20 8. A heat-resisting steel according to claim 7, wherein the Ti and/or N is replaced by Fe and C.

9. A heat-resisting steel according to claim 7 or 8,  
25 wherein the heat-resisting steel has a tempered bainite single phase structure having a prior austenite grain diameter of 100  $\mu\text{m}$  or less in average, and the precipitate types are not changed even if M, RC type precipitates, M, VC, R type precipitates, M, QC type precipitates and MC type precipitates are deposited in the bainite single phase structure and exposed to high-temperature steam of a prescribed temperature for 100,000 hour equivalent.

30 10. A heat treatment method for a heat-resisting steel, comprising:

heating to 980 to 1030°C a steel ingot which consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, cooling such that a cooling speed at the center portion of the steel ingot becomes at least 20°C/h or more, and conducting a tempering treatment.

35 11. A heat treatment method for a heat-resisting steel, comprising:

40 heating to 980 to 1030°C a steel ingot which consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, cooling such that a cooling speed at the center portion of the steel ingot becomes at least 20°C/h or more, and conducting a tempering treatment.

45 12. A heat treatment method for a heat-resisting steel, comprising:

50 heating to 980 to 1030°C a steel ingot which consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, cooling such that a cooling speed at the center portion of the steel ingot becomes at least 20°C/h or more, and conducting a tempering treatment.

55 13. A high-temperature steam turbine rotor comprising a heat-resisting steel which consists of, in percentage by weight, 0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9 of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable impurities, wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in

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percentage by weight are moved into the precipitates after a tempering heat treatment.

- 5 14. A high-temperature steam turbine rotor according to claim 13,  
wherein a total amount of the precipitates secured after operating for 100,000 hour equivalent is 2.8% or more in  
the vicinity of a portion of the high-temperature steam turbine rotor exposed to steam of the maximum temperature  
at the time of a steady operation.
- 10 15. A high-temperature steam turbine rotor according to claims 13 and 14,  
wherein the high-temperature steam turbine rotor has a tempered bainite single phase structure having a prior  
austenite grain diameter of 100  $\mu\text{m}$  or less in average, and the precipitate types are not changed even if M, RC type  
precipitates, M, VC, R type precipitates, M, QC type precipitates and MC type precipitates are deposited in the  
bainite single phase structure and exposed to steam of the maximum temperature for 100,000 hour equivalent at  
the time of a steady operation.
- 15 16. A high-temperature steam turbine rotor according to claim 13, wherein the Ti and/or N is replaced by Fe and C.
- 20 17. A high-temperature steam turbine rotor, comprising a heat-resisting steel which consists of, in percentage by weight,  
0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9  
of Mo, 0.9 to 1.4 of W, less than 0.01 of Ti, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable  
impurities,  
wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount  
of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in  
percentage by weight are moved into the precipitates after a tempering heat treatment.
- 25 18. A high-temperature steam turbine rotor according to claim 17,  
wherein a total amount of the precipitates secured after operating for 100,000 hour equivalent is 2.8% or more in  
the vicinity of a portion of the high-temperature steam turbine rotor exposed to steam of the maximum temperature  
at the time of a steady operation.
- 30 19. A high-temperature steam turbine rotor according to claims 17 and 18,  
wherein the high-temperature steam turbine rotor has a tempered bainite single phase structure having a prior  
austenite grain diameter of 100  $\mu\text{m}$  or less in average, and the precipitate types are not changed even if M, RC type  
precipitates, M, VC, R type precipitates, M, QC type precipitates and MC type precipitates are deposited in the  
bainite single phase structure and exposed to steam of the maximum temperature for 100, 000 hour equivalent at  
35 the time of a steady operation.
20. A high-temperature steam turbine rotor according to claim 17, wherein the Ti and/or N is replaced by Fe and C.
- 40 21. A high-temperature steam turbine rotor, comprising a heat-resisting steel which consists of, in percentage by weight,  
0.25 to 0.35 of C, 0.15 or less of Si, 0.2 to 0.8 of Mn, 0.3 to 0.6 of Ni, 1.6 to 1.9 of Cr, 0.26 to 0.35 of V, 0.6 to 0.9  
of Mo, 0.9 to 1.4 of W, 0.001 to 0.007 of N, 1.3 to 1.4 of a total of Mo and W/2 and the balance of Fe and inevitable  
impurities,  
wherein the heat-resisting steel consists of a bainite single phase structure securing 3.5 or more of a total amount  
of precipitates as 1.0 or more of Fe, 0.8 to 0.9 of Cr, 0.4 to 0.5 of Mo, 0.3 to 0.5 of W and 0.2 or more of V in  
45 percentage by weight are moved into the precipitates after a tempering heat treatment.
22. A high-temperature steam turbine rotor according to claim 21,  
wherein a total amount of the precipitates secured after operating for 100,000 hour equivalent is 2.8% or more in  
the vicinity of a portion of the high-temperature steam turbine rotor exposed to steam of the maximum temperature  
50 at the time of a steady operation.
- 55 23. A high-temperature steam turbine rotor according to claims 21 and 22,  
wherein the high-temperature steam turbine rotor has a tempered bainite single phase structure having a prior  
austenite grain diameter of 100  $\mu\text{m}$  or less in average, and the precipitate types are not changed even if M, RC type  
precipitates, M, VC, R type precipitates, M, QC type precipitates and MC type precipitates are deposited in the  
bainite single phase structure and exposed to steam of the maximum temperature for 100,000 hour equivalent at  
the time of a steady operation.

24. A high-temperature steam turbine rotor according to claim 21, wherein the Ti and/or N is replaced by Fe and C.

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