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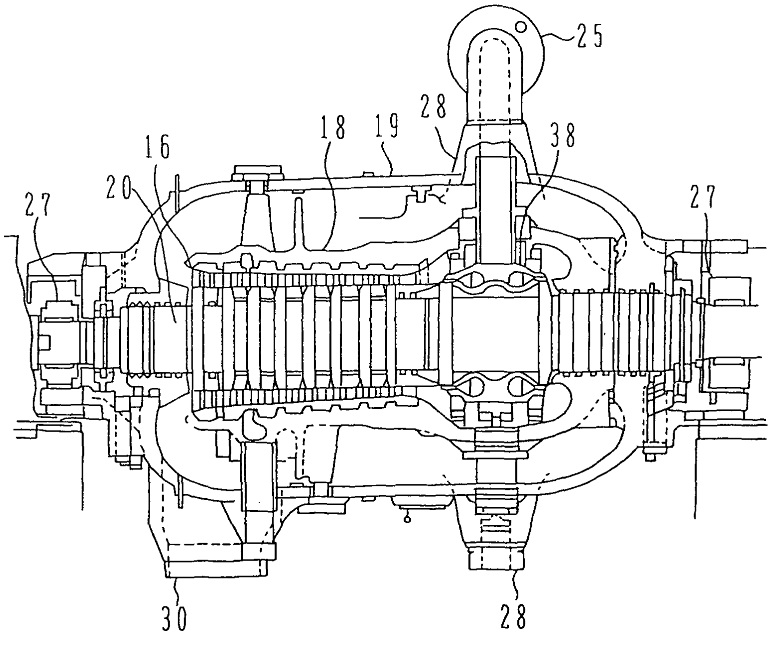
(54) High-strenght heat resisting cast steel, method of producing the steel, and applications of the steel

(57) A high-strength heat resisting cast steel which has high creep rupture strength at temperatures of 620°C or above, high toughness, and good weldability. A method of producing the steel, a steam turbine casing, a main steam valve casing, and a steam control valve casing, each casing being made of that steel, as well as a steam turbine power plant using those components are also provided. The high-strength heat resisting cast steel contains 0.06 - 0.16% by mass of C, 0.1 - 1% of Si, 0.1 - 1% of Mn, 8 - 12% of Cr, 0.1 - 1.0% of Ni, 0.7% or less of Mo, 1.9 - 3.0% of W, 0.05 - 0.3% of V, 0.01 - 0.15% of one or more of Nb, Ta and Zr in total, 0.1 - 2% of Co, 0.01 - 0.08% of N, and 0.0005 - 0.01% of B, the balance being Fe and unavoidable impurities.

FIG. 13



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a high-strength heat resisting cast steel which has high creep rupture strength at temperatures of 620°C or above and good weldability, and which is suitable for use in high- and intermediate-pressure inner casings of an ultra super critical (USC) pressure steam turbine and respective casings of a main steam valve and a steam control valve used in the USC pressure steam turbine in which temperature and pressure of main steam are not lower than 620°C and 25 MPa, respectively. Also, the present invention relates to a method of producing that steel, a steam turbine casing, a main steam valve and its casing, and a steam control valve and its casing, each casing being made of that steel, as well as a steam turbine power plant using those components.

2. Description of the Related Art

[0002] In known steam turbines with steam temperatures of 600°C or below, CrMoV low-alloy cast steel and 11CrMoVNb cast steel are used as casing materials. Meanwhile, taking into account not only exhaustion of fossil fuel, such as petroleum and coal, but also the necessity of energy saving, an improvement in power generation efficiency of the steam turbine is demanded. Because increasing the steam temperature and pressure is the most effective measure for realizing the improvement in power generation efficiency, it is tried to increase the steam temperature in a thermal power plant. However, the currently employed casing materials are not sufficient in strength when used as materials of a more efficient turbine adapted for that purpose, and materials having higher strength are required.

[0003] The high-temperature strength of the above-mentioned materials is not sufficient for use in a casing of a high-temperature steam turbine with steam temperature of 620°C or above. Patent Document 1 (JP,A 7-118812) discloses a casing made of 9%-Cr steel, but the disclosed casing has a variation in high-temperature strength. In the known typical steam turbine, the steam temperature is 600°C and the steam pressure is 25 MPa. As rotor materials, there are known 1Cr-1Mo-1/4V ferrite-base low-alloy forged steel and 11Cr-1Mo-V-Nb-N forged steel. As casing materials, there are known 1Cr-1Mo-1/4V ferrite-base low-alloy cast steel and 11Cr-1Mo-V-Nb-N cast steel. In particular, as examples having higher high-temperature strength among those materials, an austenite alloy is disclosed in Patent Document 2 (JP,A 62-180044), and martensite steels are disclosed in Patent Document 3 (JP,A 2-290950), Patent Document 4 (JP,A 4-371551), and Patent Document 5 (JP,A 9-59747).

SUMMARY OF THE INVENTION

[0004] Patent Document 5 discloses the martensite steel as a material having higher high-temperature strength than the above-mentioned known casing materials. However, the disclosed martensite steel is not sufficient in strength when used for the casing of the steam turbine with steam temperature of 620°C. This leads to the problem that the thickness of the casing must be increased and larger thermal stress is caused when the turbine is started and stopped. Further, although Patent Document 5 discloses materials of the rotor and the casing, etc., it pays no consideration to a steam turbine and a thermal power plant system adapted for an increased level of temperature.

[0005] An object of the present invention is to provide a high-strength heat resisting cast steel which has high creep rupture strength at temperatures of 620°C or above, high toughness and good weldability, a method of producing the steel, a steam turbine casing, a main steam valve and its casing, and a steam control valve and its casing, each casing being made of that steel, as well as a steam turbine power plant using those components.

[0006] To achieve the above object, the present invention provides a high-strength heat resisting cast steel containing 0.06 - 0.16% by mass of C, 0.1 - 1% of Si, 0.1 - 1% of Mn, 8 - 12% of Cr, 0.1 - 1.0% of Ni, 0.7% or less of Mo, 1.9 - 3.0% of W, 0.05 - 0.3% of V, 0.01 - 0.15% of one or more of Nb, Ta and Zr in total, 0.1 - 2% of Co, 0.01 - 0.08% of N, and 0.0005 - 0.01% of B, the balance being Fe and unavoidable impurities. Also, the present invention provides a steam turbine casing, a main steam valve and its casing, and a steam control valve and its casing, each casing being made of that steel.

[0007] In the present invention, preferably, the high-strength heat resisting cast steel contains 0.0005 - 0.04% by mass of Aℓ and 0.02% or less of O. Also, in orthogonal coordinates expressed by the relationship between [W/(Mo + 0.5W)] and (Co/W), values of [W/(Mo + 0.5W)] and (Co/W) are not larger than the values represented by linear lines interconnecting a coordinate point A (1.1, 0.90), a coordinate point B (1.5, 0.55), and a coordinate point C (1.8, 0.55).

[0008] Further, preferably, the high-strength heat resisting cast steel contains at least one of 1.5% by mass or less of Re, 0.5% or less of Nd, and 1.0% or less of Sr.

[0009] Moreover, preferably, the high-strength heat resisting cast steel has good weldability with such properties that creep rupture strength at 620°C and 10^5 hours is 98 MPa or more, and impact absorbed energy at room temperature is 29.4 J or more. To ensure higher reliability, preferably, the creep rupture strength at 620°C and 10^5 hours is 108 MPa or more, and the impact absorbed energy at room temperature is 31.4 J or more.

[0010] The method of producing the high-strength heat resisting cast steel, according to the present invention, comprises the steps of smelting, in an electric furnace, raw materials with the above-described composition; deaerating the smelted materials by vacuum ladle refining; and casting the deaerated materials into a sand mold. Further, the method of producing the high-strength heat resisting cast steel comprises the steps of annealing, at 1000 - 1150°C, the cast steel obtained after the above-described casting step; performing thermal normalizing of the annealed steel through steps of heating to 1000 - 1100°C and subsequent quick cooling; and performing two successive stages of heat treatment, i.e., primary tempering at 550 - 750°C and secondary tempering at 670 - 770°C.

[0011] The steam turbine casing, the main steam valve and its casing, and the steam control valve and its casing, according to the present invention, are produced by using the high-strength heat resisting cast steel which has the above-described composition and is produced by the above-described method. The steam turbine power plant according to the present invention is constituted by the steam turbine casing, the main steam valve, and the steam control valve. The reasons why respective ingredient elements of the high-strength heat resisting cast steel according to the present invention are limited to the above ranges will be described below.

[0012] C is an element that is required to be 0.06% or more to obtain high tensile length. However, if the C content exceeds 0.16%, the metal structure becomes unstable when exposed to high temperatures for a long time, thus resulting in reduction of long-time creep rupture strength. For that reason, the C content is limited to 0.06 - 0.16%. In particular, a preferable range is 0.08 - 0.14% and a more preferable range is 0.09-0.12%.

[0013] Mn is added as a deoxidizer. By adding 0.1% of Mn, the effect of the deoxidizer is achieved. Addition of Mn in excess of 1% reduces the creep rupture strength. In particular, a preferable range is 0.3 - 0.8% and a more preferable range is 0.4 - 0.7%.

[0014] Si is also added as a deoxidizer. Addition of Si can be reduced by employing the steel-making technology based on, e.g., the vacuum carbon deoxidation method, but Si is required to be added 0.1% or more. Also, because Si generates the harmful δ ferrite structure, the addition of Si in excess of 1% must be avoided. Reducing the Si content has the effect of preventing generation of the harmful δ ferrite structure. Accordingly, when Si is added, the Si content is required to be held 1% or less. In particular, a preferable range is 0.6% or less and a more preferable range is 0.2 - 0.6%.

[0015] Cr is effective in improving high-temperature strength and high-temperature oxidation. However, addition of Cr in excess of 12% causes the generation of the harmful δ ferrite structure, and excessive addition of Cr causes reduction of toughness. On the other hand, if the Cr content is less than 8%, oxidation resistance against high-temperature and high-pressure steam is not sufficient. In particular, a preferable range is 9.5 - 11.5% and a more preferable range is 10.0 - 11.0%.

[0016] Ni is an element that suppresses generation of δ ferrite and gives toughness. Therefore, the Ni content is required to be 0.1% at minimum. However, addition of Ni in excess of 1% reduces the creep rupture strength at temperatures of 620°C or above. For that reason, the Ni content is limited to 0.1 - 1.0%. In particular, a preferable range is 0.2 - 0.8% and a more preferable range is 0.3 - 0.7%.

[0017] W is effective in noticeably increasing the high-temperature and long-time strength. If the W content is less than 1.9%, the effect of increasing the strength is not sufficient as heat resisting cast steel when the steel is used at temperatures of 620°C or above. On the other hand, if the W content exceeds 3.0%, toughness is reduced. In particular, a preferable range is 1.95 - 2.7% and a more preferable range is 2.0 - 2.5%.

[0018] Mo is added to increase the high-temperature strength. However, when W is contained in excess of 1.9% as in the cast steel of the present invention, addition of Mo in excess of 1% reduces toughness and fatigue strength. Accordingly, the Mo content is limited to 1.0% or less. In particular, a preferable range is 0.15 - 0.7% and a more preferable range is 0.2 - 0.6%.

[0019] V is effective in increasing the creep rupture strength. If the V content is less than 0.05%, the reslting effect is not sufficient. Conversely, if the V content exceeds 0.3%, δ ferrite is generated to reduce the fatigue strength. In particular, a preferable range is 0.10 - 0.25% and a more preferable range is 0.12 - 0.23%.

[0020] Nb is a very effective element to increase the high-temperature strength. However, excessive addition of Nb generates coarse eutectic NB carbides, particularly in a large-sized steel ingot, thus causing precipitation of δ ferrite that reduces the high-temperature strength and the fatigue strength. For that reason, the Nb content is required to be held less than 0.15%. Conversely, if the Nb content is less than 0.01%, the resulting effect is not sufficient. In the case of a large-sized steel ingot, in particular, a preferable range is 0.02 - 0.12% and a more preferable range is 0.04 - 0.10%.

[0021] Ta and Zr are effective in increasing low-temperature toughness. A sufficient effect is obtained by adding 0.15% or less of Ta and 0.1% or less of Zr solely or in combination. When Ta is added 0.1% or more, addition of Nb can be omitted.

[0022] Co noticeably increases the high-temperature strength when added 0.1% or more. Such effect is presumably attributable to the interaction with W. In other words, that effect is a phenomenon specific to the alloy of the present invention which contains 1.9% or more of W. On the other hand, excessive addition of Co over 2% reduces structure stability at high temperatures and hence reduces the creep rupture strength. Therefore, the Co content is limited to 0.1 - 2%. In particular, a preferable range is 0.1 - 1.6% and a more preferable range is 0.2 - 1.2%.

[0023] N has the actions of not only precipitating a nitride of V, but also increasing the high-temperature strength in the solid solution state based on the IS effect (interaction between an interstitial solid solution element and a substitutive solid solution element) in cooperation with Mo and W. Therefore, N is required to be added 0.01% at minimum. However, addition of N in excess of 0.08% reduces ductility. For that reason, the N content is limited to 0.01 - 0.08%. In particular, a preferable range is 0.015 - 0.075% and a more preferable range is 0.015 - 0.06%.

[0024] Al is added 0.0005% or more as a deoxidizer and a crystal grain reducing agent (refiner). However, Aℓ is a strong nitride-forming element and fixates N that effectively acts to prevent creep. Particularly, addition of Aℓ in excess of 0.04% reduces the long-time creep strength at 10^4 hours or more in a high temperature range. Also, Aℓ promotes precipitation of the Laves phase in the form of a brittle intermetallic compound made of mainly W, thus causing precipitation of the Laves phase at the crystal grain boundary and reduction of the creep rupture strength at the longer-time side. In the case of excessive crystal grain refinement, in particular, the Laves phase is continuously precipitated along the crystal grain boundary. Accordingly, an upper limit of the Aℓ content is set to 0.04%. In particular, a preferable range is 0.001 - 0.035% and a more preferable range is 0.003 - 0.030%.

[0025] B is effective in increasing the high-temperature strength by the action of strengthening the crystal grain boundary and the action of causing solid solution in $M_{23}C_6$ to thereby prevent aggregation of $M_{23}C_6$-type carbides into coarser grains. That effect is obtained by adding 0.0005% of B at minimum. However, addition of B in excess of 0.01% impedes weldability. For that reason, the B content is limited to 0.0005 - 0.01%. In particular, a preferable range is 0.001 - 0.008% and a more preferable range is 0.002 - 0.007%.

[0026] The O content in excess of 0.015% reduces the high-temperature strength and toughness values, it should be kept 0.020% or less. In particular, a preferable range is 0.015% or less and a more preferable range is 0.010% or less.

[0027] In addition, it was experimentally found that Mo, W and Co among the above-mentioned ingredients greatly affect the high-temperature strength and the high-temperature structure stability and cause the action in a combined way in the steel of the present invention.

[0028] More specifically, to obtain material characteristics having both the high-temperature strength and the high-temperature structure stability at 620°C or above, it is preferable, in an addition ratio of Mo and W which are effective in increasing the creep strength, to increase the W ratio for noticeably increasing the long-time and high-temperature strength, and to reduce an addition ratio of Co and W (i.e., Co/W) for increasing the high-temperature structure stability. Stated another way, in the orthogonal coordinates expressed by [W/(Mo + 0.5W)] and (Co/W) and representing the relationship among Mo, W and Co, values of [W/(Mo + 0.5W)] and (Co/W) are preferably included in a region located under linear lines ABC interconnecting the coordinate point A (1.1, 0.90), the coordinate point B (1.5, 0.55), and the coordinate point C (1.8, 0.55).

[0029] Re noticeably increases the high-temperature strength by strengthening with the solid solution. Because excessive addition promotes embrittlement, Re is preferably added 2% or less. In consideration of Re being a rare element, a preferable range is 1.5% or less and a more preferable range is 1.2% or less from the practical point of view.

[0030] Nd increases the high-temperature strength by forming carbo-nitrides. Nd exhibits an effect even when added in small amount, and excessive addition promotes embrittlement. Therefore, Nd is preferably added 1% or less. In consideration of Nd being a rare element, a preferable range is 0.5% or less and a more preferable range is 0.3% or less from the practical point of view.

[0031] Sr strengthens the old austenite grain boundary and increases the low-temperature toughness and strength, thus increasing especially the creep rupture strength. However, excessive addition promotes formation of carbo-nitrides at the grain boundary and makes the grain boundary more brittle, which leads to reduction of the toughness and strength. Therefore, Sr is preferably added 1.0% or less. In consideration of Sr being a rare element, a preferable range is 0.8% or less and a more preferable range is 0.5% or less from the practical point of view.

[0032] In the steam turbine casing, the main steam valve, and the steam control valve using the heat resisting cast steel according to the present invention, if the δ ferrite structure exists in a mixed state, the high-temperature creep rupture strength and the low-temperature toughness are reduced. Therefore, the heat resisting cast steel preferably has the uniform tempered martensite structure. To obtain the uniform tempered martensite structure, the Cr equivalent expressed by the following formula (1) must be held 10 or less. On the other hand, the Cr equivalent must be held 4 or more because the high-temperature creep rupture strength is reduced if the Cr equivalent is too low.

$$\begin{aligned}\text{Cr equivalent (\% by mass)} &= \mathrm{Cr} + 6\mathrm{Si} + 4\mathrm{Mo} + 1.5\mathrm{W} + 11\mathrm{V} \\ &\quad 5\mathrm{Nb} - 40\mathrm{C} - 30\mathrm{N} - 30\mathrm{B} - 2\mathrm{Mn} - 4\mathrm{Ni} - 2\mathrm{Co} \quad \ldots(1)\end{aligned}$$

[0033] Reduction of P and S is effective in increasing the creep rupture strength and the low-temperature toughness. Therefore, their contents are preferably held as low as possible. Specifically, P and S are each preferably held 0.020% or less from the viewpoint of increasing the low-temperature toughness. In particular, a preferable range of P is 0.015% or less, a preferable range of S is 0.015% or less, a more preferable range of P is 0.010% or less, and a more preferable range of S is 0.010% or less.

[0034] Reduction of Sb, Sn and As is also effective in increasing the low-temperature toughness, and therefore their contents are preferably held as low as possible. Specifically, Sb is preferably held 0.0015% or less, Sn is preferably held 0.01% or less, and As is preferably held 0.02% or less from the viewpoint of the current level of the steel-making technology. More preferably, Sb is held 0.0010% or less, Sn is held 0.005% or less, and As is held 0.01% or less.

[0035] Because the steam turbine casing, the main steam valve, and the steam control valve are exposed to high-pressure steam at 620°C or above, high stress is caused therein due to inner pressure. From the viewpoint of preventing creep rupture, therefore, the casing material is required to have the creep rupture strength at 620°C and 10^5 hours of 98 MPa or more. Also, because thermal stress is caused at a relatively low material temperature when the turbine is started, the casing material is required to have the impact absorbed energy at room temperature of 29.4 J or more from the viewpoint of preventing brittle fracture. To ensure higher reliability, preferably, the creep rupture strength at 620°C and 10^5 hours is 108 MPa or more, and the impact absorbed energy at room temperature is 31.4 J or more.

[0036] In the steam turbine casing, particularly, the steel ingot is a large-sized mass having weight of about 50 tons, and the highly developed steel-making technology is required to produce a steel ingot including less defects. The high-strength heat resisting cast steel according to the present invention can be produced in the satisfactory form through the steps of smelting, in an electric furnace, alloy raw materials with the objective composition, deaerating the smelted materials by vacuum ladle refining, and casting the deaerated materials into a sand mold. By sufficiently refining and deoxidizing the materials before the casting step, the cast steel can be obtained with less casting defects such as shrinkage. The above point is similarly applied to the production of the main steam valve and the steam control valve.

[0037] Also, a large-sized steel ingot adapted for, e.g., the steam turbine casing, which can be used in steam at 620°C or above, through the steps of annealing, at 1000 - 1150°C, the heat resisting cast steel obtained as described above; performing thermal normalizing of the annealed steel through steps of heating to 1000 - 1100°C and subsequent quick cooling, and successively performing primary tempering at 550 - 750°C and secondary tempering at 670 - 770°C. If the annealing temperature and the normalizing temperature are 1000°C or below, carbo-nitrides cannot be obtained in the state of sufficient solid solution. Conversely, if those temperatures are too high, coarser crystal grains are caused. Further, by performing two successive stages of tempering, the residual austenite structure can be completely decomposed and the uniform tempered martensite structure can be obtained. As a result of producing the high-strength heat resisting cast steel by the above-described method, the steam turbine casing capable of being used in steam at 620°C or above is realized in which the creep rupture strength at 620°C and 10^5 hours is 98 MPa or more, and the impact absorbed energy at room temperature is 29.4 J or more.

[0038] Thus, the present invention can provide the ferrite-base heat resisting cast steel having high creep rupture strength at 620°C and high toughness at room temperature, which can be used for casings of an ultra super critical (USC) pressure steam turbine operated at temperatures until 650°C.

[0039] Also, by using the heat resisting cast steel of the present invention for the casings of the USC pressure steam turbine operated at temperatures until 650°C instead of the austenite heat resisting cast steel, those casings can be produced in accordance with the same design concept as that in the past. Further, since the heat resisting cast steel of the present invention has a smaller thermal expansion coefficient than the austenite heat resisting cast steel, other advantages are obtained in that quick start of the steam turbine can be more easily performed and the casings are less susceptible to damages caused by thermal fatigue.

BRIEF DESCRIPTION OF THE DRAWINGS

[0040]

Fig. 1 is a graph showing the relationship between the W content and the 10^5-hour creep rupture strength (stress);
Fig. 2 is a graph showing the relationship between the W content and the impact absorbed energy;
Fig. 3 is a graph showing the relationship between the Co content and the 10^5-hour creep rupture strength;
Fig. 4 is a graph showing the relationship between the Co content and the impact absorbed energy;
Fig. 5 is a graph showing the relationship between [W/(Mo + 0.5W)] and the 10^5-hour creep rupture strength;
Fig. 6 is a graph showing the relationship between [W/(Mo + 0.5W)] and the impact absorbed energy;
Fig. 7 is a graph showing the relationship between (Co/W) and the 10^5-hour creep rupture strength;
Fig. 8 is a graph showing the relationship between (Co/W) and the impact absorbed energy;
Fig. 9 is a graph showing the relationship between [W/(Mo + 0.5W)] and (Co/W);
Fig. 10 is a graph showing the relationship between the impact absorbed energy (vertical axis) and the creep rupture

strength (horizontal axis);

Fig. 11 is a graph showing the relationship between the creep rupture strength (vertical axis) and the impact absorbed energy (horizontal axis);

Figs. 12A-12C are schematic views showing the structure of a specimen used in a weld cracking test;

Fig. 13 is a cross-sectional view showing the structure of a high-pressure steam turbine according to the present invention;

Fig. 14 is a cross-sectional view showing the structure of an intermediate-pressure steam turbine according to the present invention;

Fig. 15 is a cross-sectional view showing the structure of a high- and intermediate-pressure integral steam turbine according to the present invention; and

Fig. 16 is a cross-sectional view of a main steam valve and a steam control valve according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0041] The best mode for carrying out the present invention will be described in detail below in connection with exemplary embodiments. It is to be noted that the present invention is not limited to those embodiments.

(First Embodiment)

[0042] Table 1, given below, shows chemical composition (% by mass) of the heat resisting cast steel according to the present invention. Assuming a thick wall portion of a large-sized casing, a sample was prepared by smelting 200 kg of raw materials in a high-frequency induction melting furnace, and casting the smelted materials into a sand mold with a thickness of 200 mm, a width of 380 mm and a height of 440 mm at maximum, thereby obtaining a cast ingot. In Table 1, samples No. 1-13 represent the steel of the present invention, and samples No. 30-35 represent the known comparative steels. Any of the samples was subjected to annealing of 1050°C × 8 hours with subsequent furnace cooling, thermal normalizing performed through steps of heating and holding of 1050°C × 8 hours and subsequent air cooling, primary tempering through steps of heating and holding of 680°C × 7 hours and subsequent air cooling, and secondary tempering through steps of heating and holding of 710°C × 7 hours and subsequent air cooling.

Table 1

	C	Si	Mn	Ni	Cr	Mo	W	V	Nb	Co	Others	Al	N	B	O	Cr Equivalent	W/(Mo+0.5W)	Co/W
No. 1	0.14	0.4	0.50	0.51	10.5	0.4	2.1	0.2	0.08	1.0	-	0.012	0.050	0.0005	0.007	8.10	1.4483	0.4762
No. 2	0.13	0.2	0.60	0.52	10.2	0.2	2.5	0.2	0.07	1.2	-	0.008	0.040	0.0005	0.008	6.41	1.7241	0.4800
No. 3	0.16	0.3	0.55	0.49	10.1	0.5	2.0	0.2	0.08	1.2	-	0.009	0.054	0.0014	0.005	5.98	1.3333	0.6000
No. 4	0.12	0.5	0.58	0.65	10.7	0.2	2.5	0.2	0.06	0.5	-	0.007	0.048	0.0052	0.004	9.59	1.7241	0.2000
No. 5	0.15	0.4	0.49	0.55	10.9	0.5	2.0	0.2	0.08	0.2	-	0.008	0.050	0.0068	0.006	9.62	1.3333	0.1000
No. 6	0.13	0.4	0.61	0.54	11.2	0.2	2.8	0.2	0.09	1.5	Sr0.3	0.020	0.050	0.0021	0.008	6.11	1.7500	0.5357
No. 7	0.14	0.5	0.62	0.25	10.4	0.4	2.9	0.2	0.04	1.5	Nd0.3	0.016	0.034	0.0091	0.009	9.62	1.5676	0.5172
No. 8	0.14	0.4	0.57	0.12	10.1	0.4	2.6	0.2	0.03	1.4		0.024	0.058	0.0014	0.010	8.55	1.5294	0.5385
No. 9	0.13	0.3	0.46	0.45	10.7	0.5	2.4	0.2	0.07	1.2	Re0.7	0.031	0.035	0.0051	0.009	9.10	1.4118	0.5000
No. 10	0.14	0.6	0.57	0.35	9.5	0.6	2.1	0.2	0.04	1.1	Ta0.02	0.017	0.071	0.0006	0.014	8.56	1.2727	0.5238
No. 11	0.15	0.5	0.58	0.57	9.7	0.5	1.9	0.2	0.06	1.1	-	0.013	0.065	0.0005	0.006	6.45	1.3103	0.5789
No. 12	0.12	0.6	0.59	0.55	10.4	0.4	2.1	0.2	0.08	1.0	-	0.010	0.042	0.0005	0.005	9.90	1.4483	0.4762
No. 13	0.10	0.5	0.54	0.52	10.2	0.7	2.0	0.2	0.07	1.4	-	0.008	0.058	0.0005	0.004	9.84	1.1765	0.7000
No. 30	0.12	0.10	0.59	0.51	10.13	0.79	2.01	0.21	0.03	2.99	Ta0.03	0.012	0.04	0.0110	0.006	3.84	1.1198	1.4876
No. 31	0.11	0.12	0.58	0.50	10.05	0.77	2.06	0.20	0.04	3.02	-	0.031	0.03	0.0054	0.006	4.60	1.1444	1.4660
No. 32	0.10	0.20	0.30	0.50	10.0	0.40	1.80	0.15	0.057	3.5	-	0.014	0.031	0.0020	0.007	2.05	1.3846	1.9444
No. 33	0.11	0.20	0.30	0.50	9.7	0.60	3.20	0.14	0.053	2.4	-	0.004	0.030	0.0120	0.008	6.85	1.4545	0.7500
No. 34	0.10	0.20	0.30	0.50	9.9	0.40	1.85	0.15	0.042	3.5	-	0.024	0.027	0.0074	0.004	2.70	1.3862	1.8919
No. 35	0.10	0.20	0.30	0.50	9.6	1.10	1.21	0.14	0.043	3.6		0.026	0.026	0.0031	0.006	4.10	0.7097	2.9752

[0043] Table 2, given below, shows the test results of tensile strength at room temperature, V-notch Charpy impact absorbed energy at 20°C, creep rupture strength at 620°C × 10^5 hours, and weld cracks.

[0044] In the samples No. 1-13 representing the steel of the present invention in which B, Mo, W and Co are added in proper amounts and the values of [W/(Mo + 0.5W)] and (Co/W) are set in the predetermined region, the creep rupture strength and the impact absorbed energy sufficiently satisfy the above-described characteristics (i.e., the creep rupture strength at 620°C × 10^5 hours ≥ 98 MPa and the impact absorbed energy at 20°C ≥ 29.4 J) which are required for the high-temperature and high-pressure turbine casing used at temperatures until 650°C.

Table 2

	Tensile Strength	Elongation	Reduction of Area	vE	10^5-Hour Rupture Strength	Weld Cracks
	MPa	%	%	J	MPa	Cracked/Not Cracked
No. 1	68.4	22.3	68.5	34.5	110	Not Cracked
No. 2	71.1	20.1	59.8	31.4	115	Not Cracked
No. 3	72.4	20.5	62.8	29.8	109	Not Cracked
No. 4	72.4	19.8	65.4	45.1	115	Not Cracked
No. 5	70.9	20.9	62.1	31.5	107	Not Cracked
No. 6	73.1	20.3	64.1	32.6	125	Not Cracked
No. 7	73.8	20.8	62.7	30.8	122	Not Cracked
No. 8	72.4	22.0	65.3	29.9	115	Not Cracked
No. 9	71.8	19.4	59.7	35.9	128	Not Cracked
No. 10	70.9	18.7	64.7	30.5	107	Not Cracked
No. 11	69.8	20.5	65.3	35.7	104	Not Cracked
No. 12	67.4	20.3	65.4	34.1	101	Not Cracked
No. 13	69.5	17.9	62.4	40.2	112	Not Cracked
No. 30	71.2	20.5	65.4	30.4	87	Not Cracked
No. 31	70.5	22.4	62.2	29.8	94	Not Cracked
No. 32	68.9	19.4	60.3	34.7	78	Not Cracked
No. 33	78.4	17.4	55.2	11.2	112	Not Cracked
No. 34	70.4	18.9	58.4	34.2	87	Not Cracked
No. 35	64.9	20.4	60.8	40.6	91	Not Cracked

[0045] Fig. 1 is a graph showing the relationship between the W content and the 10^5-hour creep rupture strength (stress). As shown in Fig. 1, in any of the comparative steel No. 32 in which the Nb content is 0.057%, No. 33 in which the Nb content is 0.053%, No. 35 in which the Nb content is 0.04%, No. 34 in which the Nb content is 0.04%, No. 31 in which the Nb content is 0.04%, and No. 30 in which the Nb content is 0.03%, the creep rupture strength is increased with an increase of the W content, and a larger effect is obtained with the higher Nb content. On the other hand, in the samples No. 1-13 representing the steel of the present invention in which the Co content is 0.2 - 1.5%, it is apparent that any of the steel samples of the present invention has higher creep rupture strength than the known steel samples having the same Nb and W contents. If the W content is 1.8% or less, the influence of the W content does not appear. However, if the W content exceeds 1.8%, the creep rupture strength is noticeably increased. Further, in the samples No. 1-13 representing the steel of the present invention, the creep rupture strength is noticeably increased with an increase of the W content at any of the Nb content of about 0.04% and the Nb content of about 0.08%.

[0046] Fig. 2 is a graph showing the relationship between the W content and the impact absorbed energy. As a result of studying influences of W upon mechanical properties, it is apparent that, for the same Nb contents as those in the above case, the impact absorbed energy is reduced as the W content increases. However, in any of the samples No. 1-13 representing the steel of the present invention in which the Co content is 0.2 - 1.5%, the impact absorbed energy is higher than the known steel samples having the same Nb and W contents. Also, in the steel samples of the present invention, reduction of the impact absorbed energy at room temperature does not appear at the W content within 3.0%. Further, in the steel samples of the present invention having the low Nb contents of 0.03 - 0.06%, the impact absorbed energy at room temperature is not reduced with an increase of the W content.

[0047] Fig. 3 is a graph showing the relationship between the Co content and the 10^5-hour creep rupture strength. As shown in Fig. 3, in the known steel samples, it is apparent that, for the same Nb contents as those in the above case, the creep rupture strength is reduced with an increase of the Co content. On the other hand, in the low- and medium-Co steel samples of the present invention in which the Co content is 0.2 - 1.5%, the creep rupture strength is increased with an increase of the Co content. Accordingly, it is apparent that, looking at both sides of a boundary corresponding to the Co content of 2%, any of the samples having the Co content below 2% has higher creep rupture strength, while in the side where the Co content is above 2%, the creep rupture strength is conversely reduced with an increase of the Co content.

[0048] Fig. 4 is a graph showing the relationship between the Co content and the impact absorbed energy. As shown in Fig. 4, any of the comparative steel samples and the steel samples of the present invention has a tendency to have higher impact absorbed energy with an increase of the Co content. However, the Co content in excess of 2% leads to the unsatisfactory result because the structure stability is reduced and the 10^5-hour creep rupture strength is also reduced as described above.

[0049] Fig. 5 is a graph showing the relationship between [W/(Mo + 0.5W)] and the 10^5-hour creep rupture strength. As shown in Fig. 5, in the samples No. 30-35 representing the comparative steels having the high Co contents, the 10^5-hour creep rupture strength is slightly reduced with an increase of [W/(Mo + 0.5W)]. On the other hand, in the steel samples of the present invention, the 10^5-hour creep rupture strength is increased with an increase of [W/(Mo + 0.5W)].

[0050] Fig. 6 is a graph showing the relationship between [W/(Mo + 0.5W)] and the impact absorbed energy. As shown in Fig. 6, in the samples No. 30-35 representing the comparative steels having the high Co contents, the impact absorbed energy is slightly reduced with an increase of [W/(Mo + 0.5W)]. On the other hand, in the steel samples of the present invention, reduction of the impact absorbed energy with an increase of [W/(Mo + 0.5W)] does not appear.

[0051] Fig. 7 is a graph showing the relationship between (Co/W) and the 10^5-hour creep rupture strength. As shown in Fig. 7, in the samples No. 30-35 representing the comparative steels having the high Co contents, at (Co/W) of 0.75 or above, the 10^5-hour creep rupture strength is reduced with an increase of (Co/W) and a reduction rate is steeper at the higher Nb content. On the other hand, in the steel samples of the present invention in which (Co/W) is 1.0 or below, the influence of (Co/W) is small and change of the 10^5-hour creep rupture strength is small when (Co/W) is in the range of 0.1 - 0.70.

[0052] Fig. 8 is a graph showing the relationship between (Co/W) and the impact absorbed energy. As shown in Fig. 8, in the known steel samples, at (Co/W) of 0.75 or above, the impact absorbed energy is increased as the value of (Co/W) increases, and the increase rate is steeper at the higher Nb content. On the other hand, in the steel samples of the present invention in which (Co/W) is in the range of 0.1 - 0.70, change of the impact absorbed energy is small.

[0053] Fig. 9 is a graph showing the relationship between [W/(Mo + 0.5W)] and (Co/W). By adjusting the value of [W/(Mo + 0.5W)] to fall in the range of 1.1 - 1.8 and the value of (Co/W) to fall in the range of 0.1 - 0.90, the casing material made of the heat resisting cast steel is obtained with the creep rupture strength at 620°C and 10^5 hours of 98 MPa or more and the impact absorbed energy at room temperature of 29.4 J, which characteristics are required when the steel is used for high- and intermediate-pressure inner casings of the high-temperature and high-pressure steam turbine operated at temperatures of 620°C or above and pressures of 25 MPa or higher, as well as for casings of the main steam valve and the steam control valve.

[0054] Fig. 10 is a graph showing the relationship between the impact absorbed energy (vertical axis) and the creep rupture strength (horizontal axis). As shown in Fig. 10, the impact absorbed energy is reduced as the creep rupture strength increases, and has the above-described correlation with respect to the Nb content. Accordingly, it is apparent that the samples No. 1-13 representing the steel of the present invention have higher impact absorbed energy than the comparative steel samples having the same Nb contents and having the same creep rupture strengths.

[0055] Fig. 11 is a graph showing the relationship between the creep rupture strength (vertical axis) and the impact absorbed energy (horizontal axis). As shown in Fig. 11, the creep rupture strength is reduced as the impact absorbed energy increases, and has the above-described correlation with respect to the Nb content. Accordingly, it is apparent that the samples No. 1-13 representing the steel of the present invention have higher creep rupture strength than the comparative steel samples having the same Nb contents and having the same impact absorbed energy.

[0056] Figs. 12A, 12B and 12C are a front view, a side view, and a cross-sectional view, respectively, showing the shape and dimensions of a specimen used in a weld cracking test made on the steel of the present invention. Weldability was evaluated by an inclined Y-groove weld cracking test in conformity with JIS Z3158. Welding was performed by setting each of the preheating temperature, the inter-pass temperature, and the post-heating start temperature to 150°C, and by using a coated arc-welding electrode containing C in amount slightly smaller than that in the base material (matrix), 0.5% or thereabout of Si, 1.5% or thereabout of Mn, 0.9% of Ni, 1.0% of Mo, the amount of each of those elements being slightly larger than that in the base material, as well as Cr, Nb, V and N each in the same amount as that in the base material. Post-heat treatment was performed at 400°C × 30 minutes. As seen from Table 2, the steel samples of the present invention caused no weld cracks and exhibited good weldability.

[0057] Thus, according to the first embodiment, the ferrite-base heat resisting cast steel having high creep rupture strength at 620°C and high toughness at room temperature can be obtained, and it can be suitably used for the casings of the ultra super critical (USC) pressure steam turbine operated at temperatures until 650°C, the main steam valve, and the steam control valve.

[0058] Also, by using the heat resisting cast steel of the present invention for the casings of the USC pressure steam turbine operated at temperatures until 650°C, the main steam valve, and the steam control valve instead of the austenite heat resisting cast steel, those casings can be produced in accordance with the same design concept as that in the past. Further, since the heat resisting cast steel of the present invention has a smaller thermal expansion coefficient than the austenite heat resisting cast steel, other advantages are obtained in that quick start of the steam turbine can be more easily performed and the casings are less susceptible to damages caused by thermal fatigue.

(Second Embodiment)

[0059] Fig. 13 is a cross-sectional view showing the structure of a high-pressure steam turbine using the high-strength heat resisting cast steel according to the present invention. Fig. 14 is a cross-sectional view showing the structure of an intermediate-pressure steam turbine using the high-strength heat resisting cast steel according to the present invention. The high-pressure steam turbine includes an inner casing 18, an outer casing 19 surrounding the inner casing 18, and a high-pressure rotor shaft 20 provided with high-pressure rotor blades 16 implanted to it and disposed inside those casings. The intermediate-pressure steam turbine includes an inner casing 21, an outer casing 22 surrounding the inner casing 21, and an intermediate-pressure rotor shaft 24 provided with intermediate-pressure rotor blades 17 implanted to it and disposed inside those casings. High-temperature and high-pressure steam obtained by a boiler passes through a main steam pipe and flows into a main steam inlet 28 through a flange and elbow 25 constituting a main steam section. The steam is then introduced to the rotor blade in the double-flow first stage through a nozzle box 38. Stator nozzles are disposed corresponding to the rotor blades.

[0060] In this second embodiment, a steam turbine power plant is constituted by the high-pressure steam turbine (HP) and the intermediate-pressure steam turbine (IP) which are connected in tandem. The HP has the double-flow first stage and includes eight stages in each side. Stator nozzles are disposed corresponding to the rotor blades in both the sides. Each rotor blade is of the saddle-like dovetailed type and has double tenons.

[0061] The IP is used to rotate a generator in cooperation with the HP by utilizing steam obtained by heating the steam, which is exhausted from the HP, to 625°C again by a reheater, and it is rotated at rotation speed of 3000 rpm. Similarly to the HP, the IP has an intermediate-pressure inner compartment (casing) 21 and an intermediate-pressure outer compartment (casing) 22, and further includes stator nozzle corresponding to the intermediate-pressure rotor blades 17. The intermediate-pressure rotor blades 17 are constituted with two flow sections each including six stages and are arranged in substantially bilateral symmetry in the longitudinal direction of the intermediate-pressure rotor shaft 24.

[0062] In this embodiment, in both the HP and LP, the outer casings 19 and 22, the inner casings 18 and 21, and respective casings of a main steam valve and a steam control valve (described later) were each made of the sample No. 4 cast steel in Table 1 described above in connection with the first embodiment. Particularly, the inner casings were each produced through the steps of smelting, in an electric furnace, 50 tons of alloy raw materials with the objective composition, deaerating the smelted materials by vacuum ladle refining, and casting the deaerated materials into a sand mold.

[0063] The obtained trial cast steel was successively subjected to annealing of 1050°C × 10 hours with subsequent furnace cooling, thermal normalizing performed through steps of heating and holding of 1050°C × 10 hours and subsequent blast air cooling, primary tempering of 570°C × 12 hours, and secondary tempering of 730°C × 12 hours. As a result of cutting and examining the trial casing having the fully tempered martensite structure, it was proved that the trial casing satisfied the characteristics (i.e., the creep rupture strength at 620°C and 10^5 hours ≥ 98 MPa and the impact absorbed energy at room temperature ≥ 29.4 J) required for the casing of the high-temperature and the high-pressure turbine operated at 620°C and 25 MPa, and it caused no cracks in the above-described weld cracking test.

[0064] Thus, according to the second embodiment, the ferrite-base heat resisting cast steel having high creep rupture strength at 620°C and high toughness at room temperature can be obtained, and it can be suitably used for, e.g., the casings of the ultra super critical (USC) pressure steam turbine operated at temperatures until 650°C.

[0065] Also, by using the heat resisting cast steel of the present invention for the casings of the USC pressure steam turbine operated at temperatures until 650°C instead of the austenite heat resisting cast steel, those casings can be produced in accordance with the same design concept as that in the past. Further, since the heat resisting cast steel of the present invention has a smaller thermal expansion coefficient than the austenite heat resisting cast steel, other advantages are obtained in that quick start of the steam turbine can be more easily performed and the casings are less susceptible to damages caused by thermal fatigue.

[0066] The steam turbine power plant of this embodiment further includes two low-pressure steam turbines (LPs) which are connected in tandem and have substantially the same structure. In each LP, last-stage and other rotor blades are disposed in eight stages in each of the left and right sides and are arranged in substantially bilateral symmetry. Stator nozzles are disposed corresponding to the rotor blades. A low-pressure rotor shaft is made of forged steel having the fully tempered bainite structure of a super-clean material containing 3.75% of Ni, 1.75% of Cr, 0.4% of Mo, 0.15% of V, 0.25% of C, 0.05% of Si, and 0.10% of Mn, the balance being Fe. Any of the rotor blades and the stator nozzles in stages other than the last stage is made of 12%-Cr steel containing 0.1% of Mo.

[0067] The last-stage rotor blade has an airfoil height of 43 inches. An airfoil of the long blade having the airfoil height of 43 inches, against which high-speed steam impinges, is coated with an erosion shield formed by joining a stellite sheet made of a Co-base alloy by welding in order to prevent erosion caused by water droplets in the steam.

[0068] The 43-inch long blade is produced through a series of steps of smelting by the electroslag remelting process, forging, and heat treatment. The long blade is made of martensite steel containing 0.08 - 0.18% by mass of C, 0.25% or less of Si, 0.90% or less of Mn, 8.0 - 13.0% of Cr, 2 - 3% of Ni, 1.5 - 3.0% of Mo, 0.05 - 0.35% of V, 0.02 - 0.20% of one or more of Nb and Ta in total, and 0.02 - 0.10% of N. Further, the long blade exhibits the tensile strength at room temperature of 120 kgf/mm^2 or more and has the fully tempered martensite structure. As the mechanical properties of the 43-inch long blade, more preferably, the tensile strength is 128.5 kgf/mm^2 or more and the V-notch Charpy impact value at 20°C is 4 kgf-m/cm^2 or more.

[0069] The high-temperature and high-pressure steam turbine power plant according to this embodiment comprises mainly a coal firing boiler, one HP, one IP, two LPs, a condenser, a condensing pump, a low-pressure feedwater heater system, a deaerator, a booster pump, a feedwater pump, and a high-pressure feedwater heater system. More specifically, ultra high-temperature and high-pressure steam generated in the boiler enters the HP in which motive power is produced. Then, the steam is reheated by the boiler and enters the IP in which motive power is produced. The steam exhausted from the IP enters the LP in which motive power is produced, followed by being condensed in the condenser. The condensed water is sent to the low-pressure feedwater heater system and the deaerator by the condensing pump. The feedwater deaerated in the deaerator is sent to the high-pressure feedwater heater system by the booster pump and the condensing pump. After the water temperature is raised in the high-pressure feedwater heater system, the feedwater is returned to the boiler. In the boiler, the feedwater is converted to high-temperature and high-pressure steam through an economizer, an evaporator and a superheater.

[0070] Instead of the power plant of this embodiment, a tandem compound power plant may be constituted in which one HP, one IP, and one or two LPs are connected in tandem to rotate one generator, each of HP, IP and LP having similar structures to those described above.

[0071] Thus, according to this second embodiment, the steam turbine power plant can be obtained which has high thermal efficiency and is suitable for use with, e.g., the steam turbine casings having the long-time creep rupture strength and toughness which are required under steam temperature condition of 620 - 650°C.

[0072] Also, by using the heat resisting cast steel of the present invention for the casings of the USC pressure steam turbine operated at temperatures until 650°C, the main steam valve, and the steam control valve instead of the austenite heat resisting cast steel, those casings can be produced in accordance with the same design concept as that in the past. Further, since the heat resisting cast steel of the present invention has a smaller thermal expansion coefficient than the austenite heat resisting cast steel, other advantages are obtained in that quick start of the steam turbine can be more easily performed and the casings are less susceptible to damages caused by thermal fatigue.

(Third Embodiment)

[0073] Fig. 15 is a cross-sectional view showing the structure of a high- and intermediate-pressure integral steam turbine used in a steam turbine power plant with steam temperature of 620°C and output capacity of 600 MW. The power plant of this third embodiment is of the tandem compound double-flow type, and the last-stage blade height in the LP is 43 inches. A rotation speed of 3000 rpm is obtained by the high- and intermediate-pressure integral steam turbine (HP-IP) and one LP (C) or two LPs (D). Components used in a high-temperature region are each made of main materials shown in Table 1, which constitute the steel of the present invention. The steam temperature and pressure in the high-pressure section (HP) are 600°C and 250 kgf/cm^2. In the intermediate-pressure section (IP), the steam temperature is heated to 600°C by a reheater and operation is performed at pressure of 45 - 65 kgf/cm^2. Steam having temperature of 400°C enters the low-pressure section (LP) and is sent to a condenser under vacuum of 722 mmHg at 100°C or below.

[0074] In the (HP-IP), the high-pressure side steam turbine includes an inner casing 18 and an outer casing 19 surrounding the inner casing 18, whereas the intermediate-pressure steam turbine includes an inner casing 21 and an outer casing 22 surrounding the inner casing 21. A high- and intermediate-pressure integral rotor shaft 23 provided with high-pressure rotor blades 16 and intermediate-pressure rotor blades 17 implanted to the rotor shaft is disposed inside those casings. The high-pressure and high-temperature steam obtained by the boiler passes through a main steam pipe and flows into a main steam inlet 28 through a flange and elbow 25 constituting a main steam section. The steam is then introduced to the rotor blade in the first stage through a nozzle box 38. The rotor blades are disposed in eight stages on the high-pressure side in substantially a left half in Fig. 15 and six stages on the intermediate-pressure side in substantially a right half in Fig. 15. Stator nozzles are disposed corresponding to the rotor blades. Each rotor blade is of the saddle- or nearly π-like dovetailed type and has double tenons.

[0075] In this third embodiment, in the (HP-IP), the outer casings 19 and 22 and the inner casings 18 and 21, and respective casings of a main steam valve and a steam control valve (described later) were each made of the sample No. 4 cast steel in Table 1 described above in connection with the first embodiment. As in the second embodiment, those casings were each produced through the steps of smelting, in an electric furnace, 50 tons of alloy raw materials with the objective composition, deaerating the smelted materials by vacuum ladle refining, and casting the deaerated materials into a sand mold.

[0076] Further, in this third embodiment, those casings also had the fully tempered martensite structure. As a result of cutting and examining each trial casing, it was proved that the trial casing satisfied the characteristics (i.e., the creep rupture strength at 620°C and 10^5 hours $\geq$ 98 MPa and the impact absorbed energy at room temperature $\geq$ 29.4 J) required for the casing of the high-temperature and the high-pressure turbine operated at 620°C and 25 MPa, and it caused no cracks in the above-described weld cracking test.

[0077] Thus, according to the third embodiment, the ferrite-base heat resisting cast steel having high creep rupture strength at 620°C and high toughness at room temperature can be obtained, and it can be suitably used for, e.g., the casings of the ultra super critical (USC) pressure steam turbine operated at temperatures until 650°C.

[0078] Also, by using the heat resisting cast steel of the present invention for the casings of the USC pressure steam turbine operated at temperatures until 650°C instead of the austenite heat resisting cast steel, those casings can be produced in accordance with the same design concept as that in the past. Further, since the heat resisting cast steel of the present invention has a smaller thermal expansion coefficient than the austenite heat resisting cast steel, other advantages are obtained in that quick start of the steam turbine can be more easily performed and the casings are less susceptible to damages caused by thermal fatigue.

[0079] In the steam turbine power plant of this embodiment, one or two low-pressure steam turbines (LPs) are connected in tandem and have substantially the same structure as that in the second embodiment. In each LP, last-stage and other rotor blades are disposed in eight stages in each of the left and right sides and are arranged in substantially bilateral symmetry, thus enabling power generation with an output capacity of 1050 MW. Further, the last-stage rotor blade has an airfoil height of 43 inches and is made of the 12%-Cr steel as in the above-described case. A low-pressure rotor shaft, the rotor blades and the stator nozzles in stages other than the last stage, and inner and outer casings are each produced in a similar manner.

[0080] An airfoil of the long blade having the airfoil height of 43 inches, against which high-speed steam impinges, is coated with an erosion shield formed by joining a stellite sheet made of a Co-base alloy by welding in order to prevent erosion caused by water droplets in the steam.

[0081] The 43-inch long blade is produced, as in the second embodiment, through a series of steps of smelting by the electroslag remelting process, forging, and heat treatment. The long blade has the fully tempered martensite structure exhibiting the tensile strength at room temperature of 120 kgf/mm^2 or more, preferably 128.5 kgf/mm^2 or more, and the V-notch Charpy impact value at 20°C of 4 kgf-m/cm^2 or more.

[0082] According to this third embodiment, the steam turbine power plant can be obtained which has high thermal efficiency and is suitable for use with, e.g., the steam turbine casings having the long-time creep rupture strength and toughness which are required under steam temperature condition of 620 - 650°C.

(Fourth Embodiment)

[0083] Fig. 16 is a cross-sectional view of a main steam valve and a steam control valve used in a steam turbine power plant, which are formed in an integral structure. In this fourth embodiment, the main steam sent from the boiler to the high-pressure steam turbine and the high- and intermediate-pressure integral steam turbine in the steam turbine power plant of the second or third embodiment is supplied to a main steam valve 32 through a main steam inlet 34 and the amount of steam supplied through a steam outlet 35 is controlled by a steam control valve 33.

[0084] In this embodiment, a casing of each of the main steam valve and the steam control valve was made of the sample No. 4 cast steel in Table 1 described above in connection with the first embodiment and was produced through the steps of smelting, in an electric furnace, alloy raw materials with the objective composition, deaerating the smelted materials by vacuum ladle refining, and casting the deaerated materials into a sand mold. The obtained trial casing was subjected to heat treatment and a weld cracking test in a similar manner to those in the second embodiment.

[0085] As a result, it was proved that the trial casing satisfied the characteristics (i.e., the creep rupture strength at 620°C and 10^5 hours $\geq$ 98 MPa and the impact absorbed energy at room temperature $\geq$ 29.4 J) required for the casing of the high-temperature and the high-pressure turbine operated at 620°C and 25 MPa, and it caused no cracks in the above-described weld cracking test.

[0086] Thus, according to the fourth embodiment, the ferrite-base heat resisting cast steel having high creep rupture strength at 620°C and high toughness at room temperature can be obtained, and it can be suitably used for the respective casings of the main steam valve and the steam control valve in the ultra super critical (USC) pressure steam turbine operated at temperatures until 650°C. In other words, the fourth embodiment can also provide similar advantages to those in the above-described embodiments.

[0087] Features, components and specific details of the structures of the above-described embodiments may be exchanged or combined to form further embodiments optimized for the respective application. As far as those modifications are readily apparent for an expert skilled in the art they shall be disclosed implicitly by the above description without specifying explicitly every possible combination, for the sake of conciseness of the present description.

Claims

1. A high-strength heat resisting cast steel containing 0.06 - 0.16% by mass of C, 0.1 - 1% of Si, 0.1 - 1% of Mn, 8 - 12% of Cr, 0.1 - 1.0% of Ni, 0.7% or less of Mo, 1.9 - 3.0% of W, 0.05 - 0.3% of V, 0.01 - 0.15% of one or more of Nb, Ta and Zr in total, 0.1 - 2% of Co, 0.01 - 0.08% of N, and 0.0005 - 0.01% of B, the balance being Fe and unavoidable impurities.

2. The high-strength heat resisting cast steel according to Claim 1, wherein $A\ell$ is 0.0005 - 0.04% by mass and O is 0.02% or less.

3. The high-strength heat resisting cast steel according to Claim 1 or 2, wherein in orthogonal coordinates expressed by the relationship between [W/(Mo + 0.5W)] and (Co/W), values of [W/(Mo + 0.5W)] and (Co/W) are not larger than the values represented by linear lines interconnecting a coordinate point A (1.1, 0.90), a coordinate point B (1.5, 0.55), and a coordinate point C (1.8, 0.55).

4. The high-strength heat resisting cast steel according to any one of Claims 1 to 3, wherein the steel contains at least one of 1.5% by mass or less of Re, 0.5% or less of Nd, and 1.0% or less of Sr.

5. The high-strength heat resisting cast steel according to any one of Claims 1 to 3, wherein creep rupture strength at 620°C and 10^5 hours is 98 MPa or more, and impact absorbed energy at room temperature is 29.4 J or more.

6. A method of producing a high-strength heat resisting cast steel, the method comprising the steps of:

   smelting, in an electric furnace, raw materials with composition containing 0.06 - 0.16% by mass of C, 0.1 - 1% of Si, 0.1 - 1% of Mn, 8 - 12% of Cr, 0.1 - 1.0% of Ni, 0.7% or less of Mo, 1.9 - 3.0% of W, 0.05 - 0.3% of V, 0.01 - 0.15% of one or more of Nb, Ta and Zr in total, 0.1 - 2% of Co, 0.01 - 0.08% of N, and 0.0005 - 0.01% of B, the balance being Fe and unavoidable impurities;
   deaerating the smelted materials by vacuum ladle refining; and
   casting the deaerated materials into a sand mold.

7. A method of producing a high-strength heat resisting cast steel, the method comprising the steps of:

   annealing, at 1000-1150°C, cast steel with composition containing 0.06 - 0.16% by mass of C, 0.1 - 1% of Si, 0.1 - 1% of Mn, 8 - 12% of Cr, 0.1 - 1.0% of Ni, 0.7% or less of Mo, 1.9 - 3.0% of W, 0.05 - 0.3% of V, 0.01 - 0.15% of one or more of Nb, Ta and Zr in total, 0.1 - 2% of Co, 0.01 - 0.08% of N, and 0.0005 - 0.01% of B, the balance being Fe and unavoidable impurities;
   performing thermal normalizing of the annealed steel through steps of heating to 1000 - 1100°C and subsequent quick cooling; and
   performing successively primary tempering at 550 - 750°C and secondary tempering at 670 - 770°C.

8. The method of producing the high-strength heat resisting cast steel according to Claim 6 or 7, wherein the steel further contains 0.0005 - 0.04% by mass of $A\ell$ and 0.02% or less of O.

9. A steam turbine casing made of the high-strength heat resisting cast steel according to any one of Claims 1 to 5.

10. A method of producing a steam turbine casing, wherein the method includes a step of obtaining a casing material

by the method of producing the high-strength heat resisting cast steel according to any one of Claims 6 to 8.

11. A steam turbine comprising a rotor shaft including implanted rotor blades, an inner casing including stator nozzles implanted corresponding to said rotor blades and covering said rotor shaft including said implanted rotor blades, and an outer casing covering said inner casing,
wherein said inner casing is constituted by the steam turbine casing according to Claim 9.

12. A main steam valve for controlling supply and stop of main steam obtained by a boiler with respect to a steam turbine, wherein a casing of said main steam valve is made of the high-strength heat resisting cast steel according to any one of Claims 1 to 5.

13. A method of producing a main steam valve for controlling supply and stop of main steam obtained by a boiler with respect to a steam turbine,
wherein the method includes a step of obtaining a casing material of said main steam valve by the method of producing the high-strength heat resisting cast steel according to any one of Claims 6 to 8.

14. A steam control valve for controlling a supply amount of main steam obtained by a boiler through a main steam valve which controls supply and stop of the main steam with respect to a steam turbine,
wherein a casing of said steam control valve is made of the high-strength heat resisting cast steel according to any one of Claims 1 to 5.

15. A method of producing a steam control valve for controlling a supply amount of main steam obtained by a boiler through a main steam valve which controls supply and stop of the main steam with respect to a steam turbine,
wherein the method includes a step of obtaining a casing material of said steam control valve by the method of producing the high-strength heat resisting cast steel according to any one of Claims 6 to 8.

16. A steam turbine power plant including any of a set of a high-pressure steam turbine, an intermediate-pressure steam turbine, and two low-pressure steam turbines connected in tandem, and a set of a high- and intermediate-pressure integral steam turbine and a low-pressure steam turbine,
wherein at least one of said high-pressure steam turbine, said intermediate-pressure steam turbine, and said high- and intermediate-pressure integral steam turbine is constituted by the steam turbine according to Claim 11.

17. A steam turbine power plant including any of a set of a high-pressure steam turbine, an intermediate-pressure steam turbine, and two low-pressure steam turbines connected in tandem, and a set of a high- and intermediate-pressure integral steam turbine and a low-pressure steam turbine, said power plant further including a main steam valve for controlling supply and stop of main steam obtained by a boiler and a steam control valve for controlling a supply amount of the main steam through a main steam valve,
wherein at least one of said main steam valve and said steam control valve is constituted by the main steam valve and the steam control valve according to Claims 12 and 14.

FIG. 1

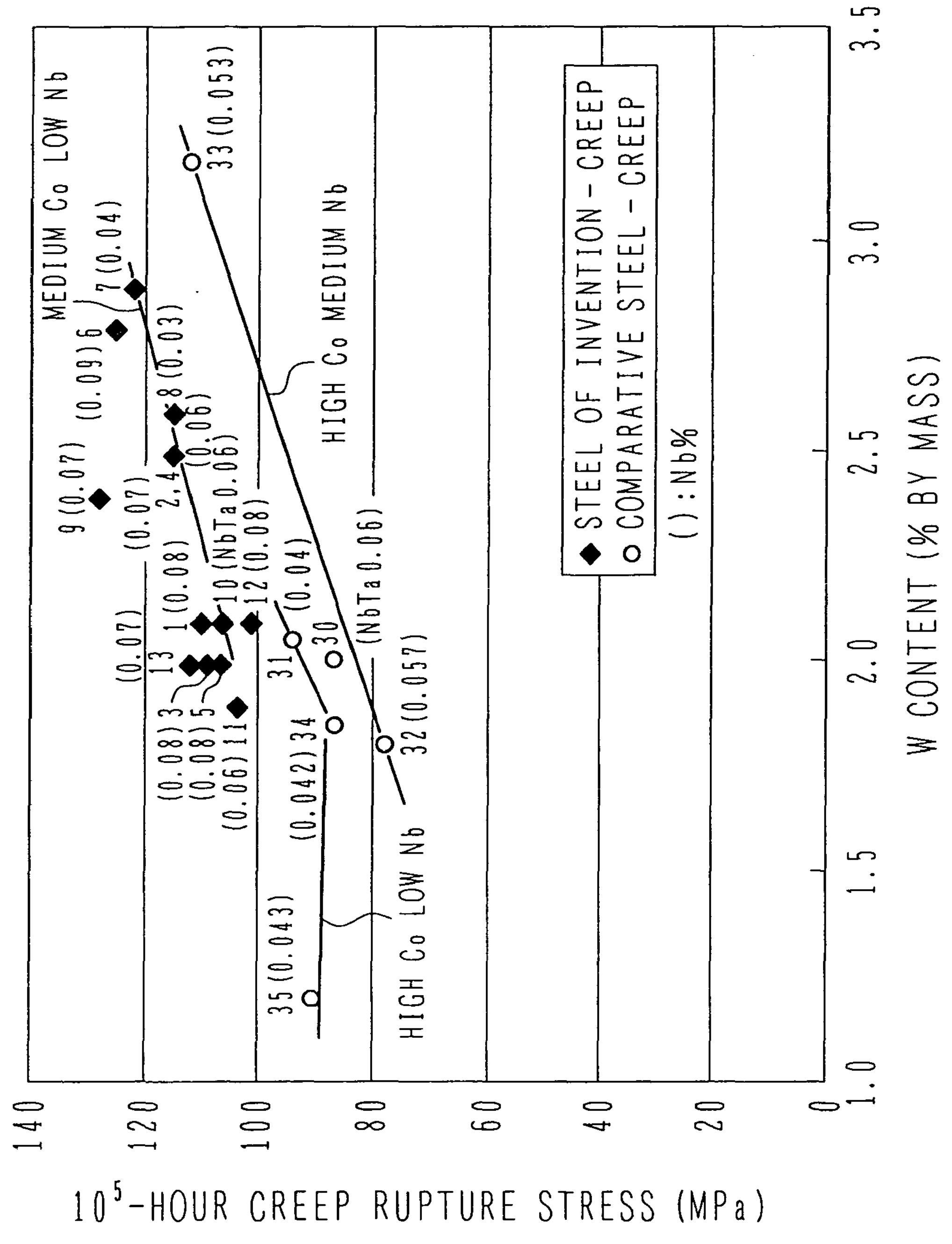

10^5-HOUR CREEP RUPTURE STRESS (MPa)
140
120
100
80
60
40
20
0
1.0
1.5
2.0
2.5
3.0
3.5
W CONTENT (% BY MASS)
◆ STEEL OF INVENTION - CREEP
○ COMPARATIVE STEEL - CREEP
( ) : Nb%
MEDIUM Co LOW Nb
HIGH Co MEDIUM Nb
HIGH Co LOW Nb
9 (0.07)
(0.09) 6
7 (0.04)
8 (0.03)
(0.07)
2, 4
(0.06)
(0.06)
1 (0.08)
10 (NbTa 0.06)
12 (0.08)
(0.07)
13
(0.08) 3
(0.08) 5
(0.06) 11
(0.04)
31
30
(NbTa 0.06)
(0.042) 34
32 (0.057)
33 (0.053)
35 (0.043)

FIG. 2

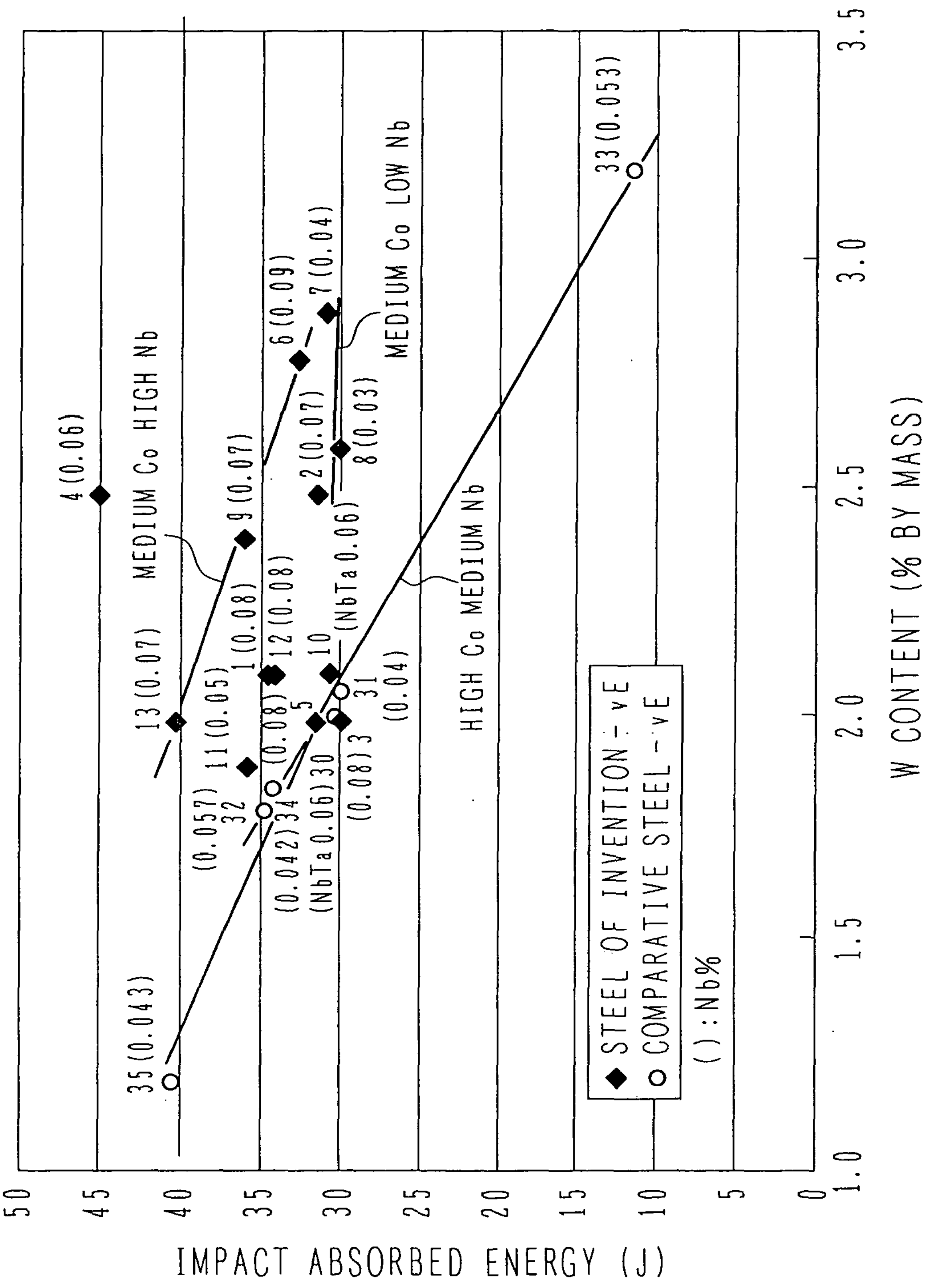

IMPACT ABSORBED ENERGY (J)
50
45
40
35
30
25
20
15
10
5
0
W CONTENT (% BY MASS)
1.0
1.5
2.0
2.5
3.0
3.5
35(0.043)
(0.057)
32
11(0.05)
13(0.07)
MEDIUM Co HIGH Nb
1(0.08)
9(0.07)
4(0.06)
(0.042)34
(0.08)
12(0.08)
(NbTa0.06)30
5
10
(NbTa0.06)
2(0.07)
6(0.09)
7(0.04)
(0.08)3
31
(0.04)
8(0.03)
MEDIUM Co LOW Nb
HIGH Co MEDIUM Nb
33(0.053)
◆ STEEL OF INVENTION - vE
○ COMPARATIVE STEEL - vE
( ):Nb%

FIG.3

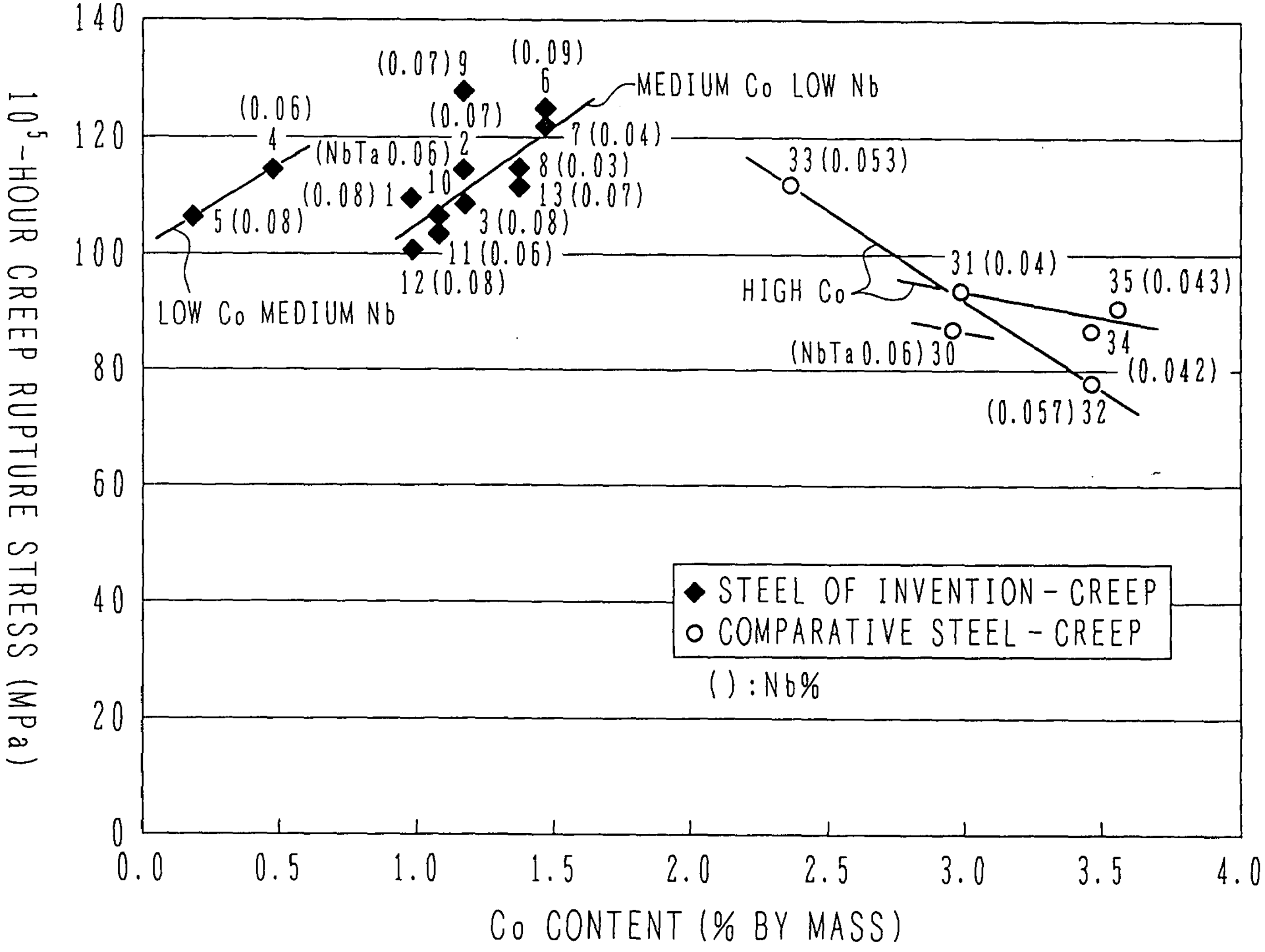

140
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
10^5-HOUR CREEP RUPTURE STRESS (MPa)
Co CONTENT (% BY MASS)
(0.06)
4
(NbTa 0.06)
5 (0.08)
LOW Co MEDIUM Nb
(0.07) 9
(0.09)
6
(0.07)
2
10
(0.08) 1
3 (0.08)
11 (0.06)
12 (0.08)
7 (0.04)
8 (0.03)
13 (0.07)
MEDIUM Co LOW Nb
33 (0.053)
31 (0.04)
HIGH Co
(NbTa 0.06) 30
35 (0.043)
34
(0.042)
(0.057) 32
◆ STEEL OF INVENTION - CREEP
○ COMPARATIVE STEEL - CREEP
( ) : Nb%

FIG. 4

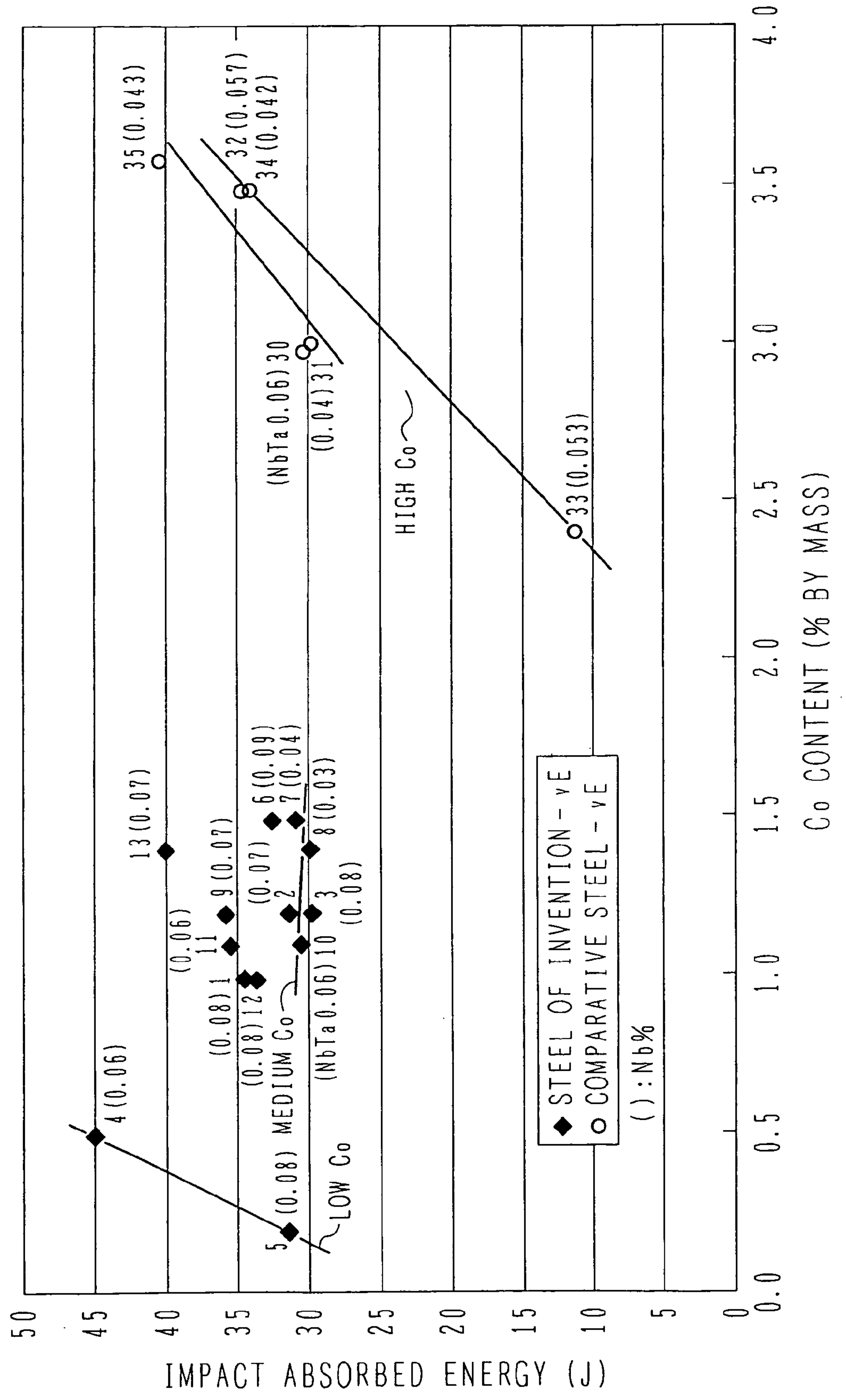

IMPACT ABSORBED ENERGY (J)
50
45
40
35
30
25
20
15
10
5
0
Co CONTENT (% BY MASS)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
◆ STEEL OF INVENTION - vE
○ COMPARATIVE STEEL - vE
( ) : Nb%
4 (0.06)
5 (0.08)
LOW Co
(0.08) 1
(0.06)
11
9 (0.07)
13 (0.07)
(0.08) 12
MEDIUM Co
(NbTa 0.06) 10
2
(0.07)
3
(0.08)
6 (0.09)
7 (0.04)
8 (0.03)
35 (0.043)
32 (0.057)
34 (0.042)
(NbTa 0.06) 30
(0.04) 31
HIGH Co
33 (0.053)

FIG.5

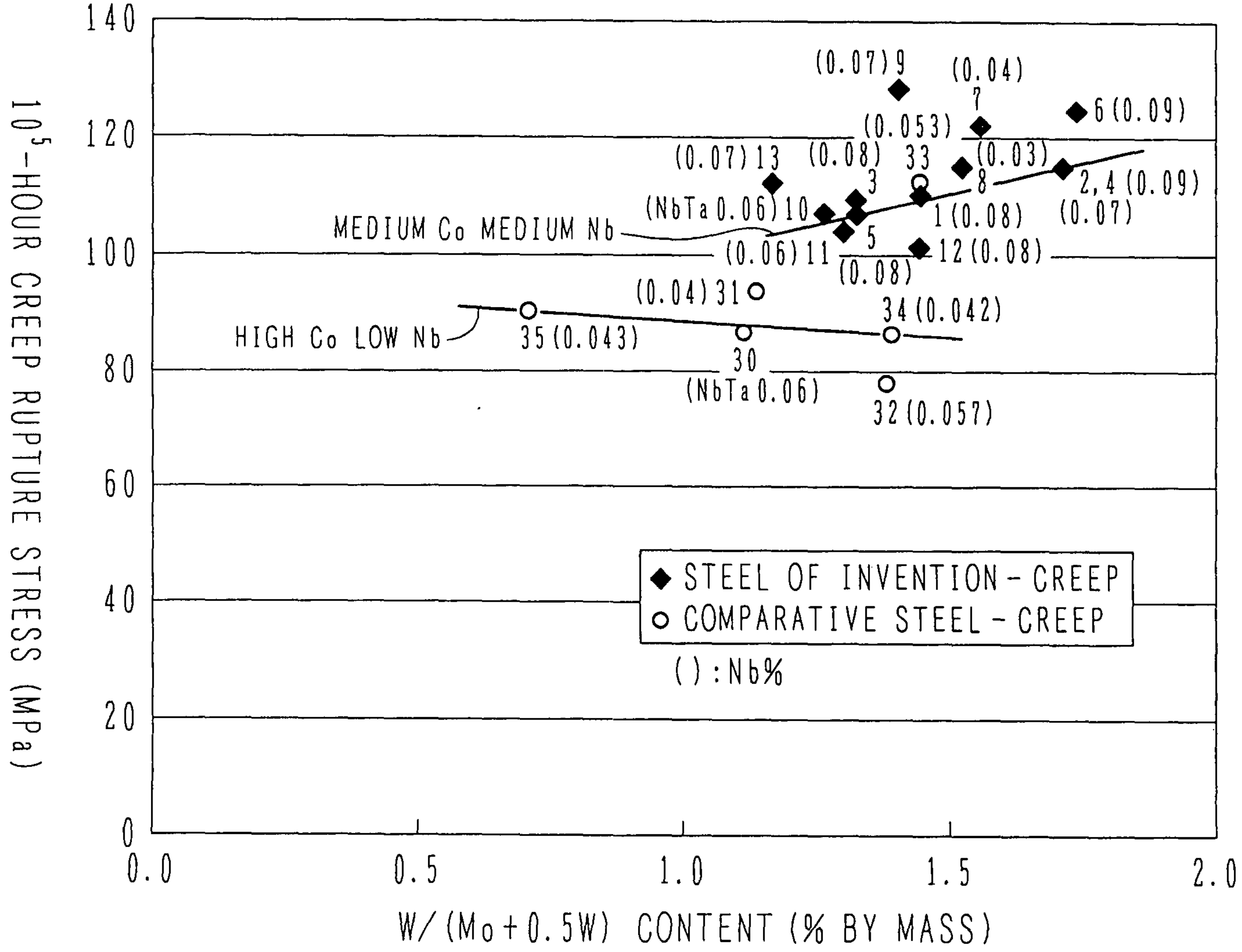

(0.07) 9
(0.04)
7
6 (0.09)
(0.053)
(0.07) 13
(0.08)
33
(0.03)
3
8
2, 4 (0.09)
(NbTa 0.06) 10
1 (0.08)
(0.07)
MEDIUM Co MEDIUM Nb
5
12 (0.08)
(0.06) 11
(0.08)
(0.04) 31
34 (0.042)
HIGH Co LOW Nb
35 (0.043)
30
(NbTa 0.06)
32 (0.057)
◆ STEEL OF INVENTION - CREEP
○ COMPARATIVE STEEL - CREEP
( ) : Nb%
140
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
10^5-HOUR CREEP RUPTURE STRESS (MPa)
W/(Mo+0.5W) CONTENT (% BY MASS)

FIG. 6

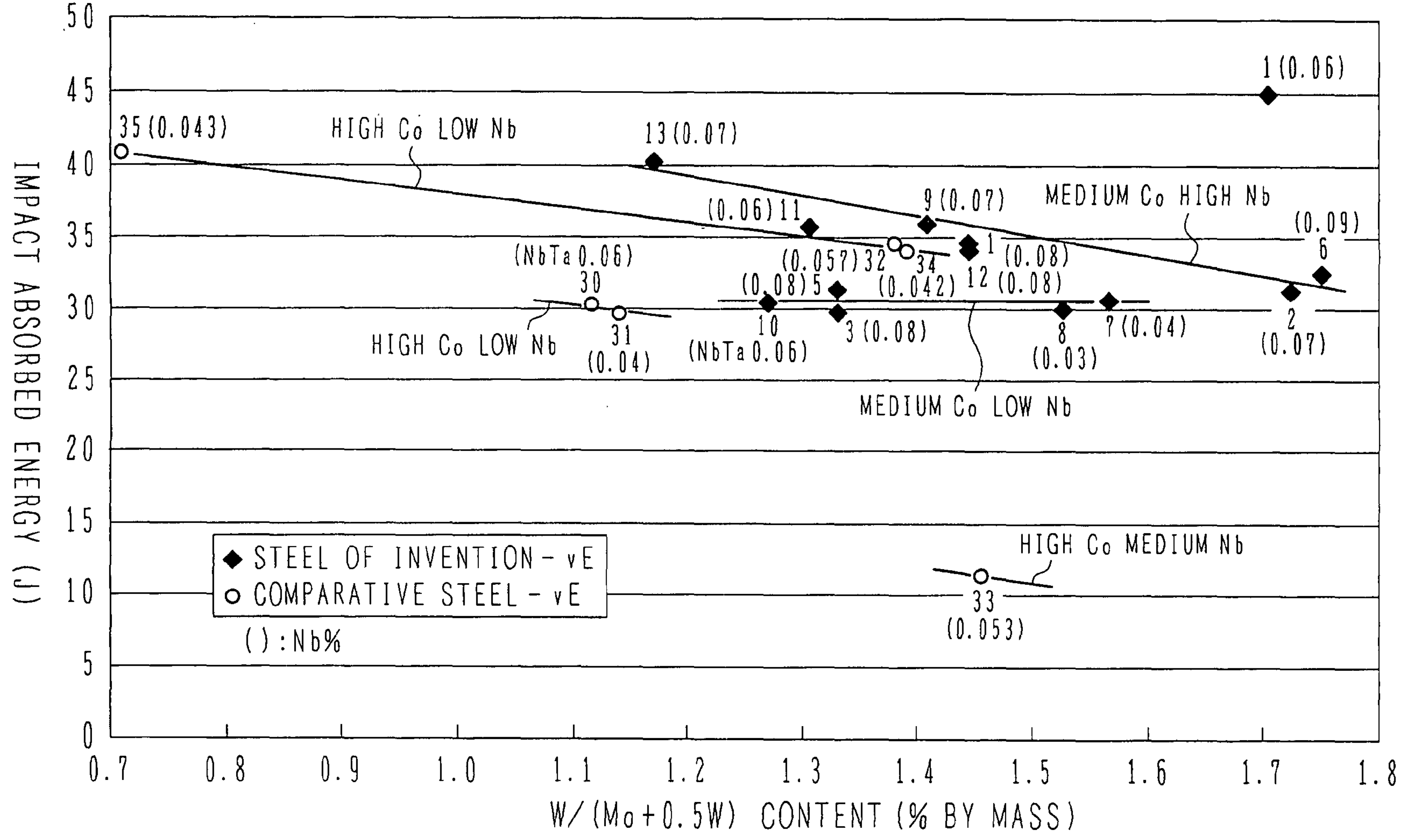

50
45
40
35
30
25
20
15
10
5
0
IMPACT ABSORBED ENERGY (J)
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
W/(Mo+0.5W) CONTENT (% BY MASS)
◆ STEEL OF INVENTION - vE
○ COMPARATIVE STEEL - vE
( ):Nb%
35(0.043)
HIGH Co LOW Nb
13(0.07)
1(0.06)
9(0.07)
MEDIUM Co HIGH Nb
(0.09)
6
(0.06)11
(0.057)32
34
(0.042)
1
(0.08)
12 (0.08)
(0.08)5
(NbTa 0.06)
30
31
(0.04)
HIGH Co LOW Nb
10
(NbTa 0.06)
3 (0.08)
8
(0.03)
7 (0.04)
2
(0.07)
MEDIUM Co LOW Nb
HIGH Co MEDIUM Nb
33
(0.053)

FIG. 7

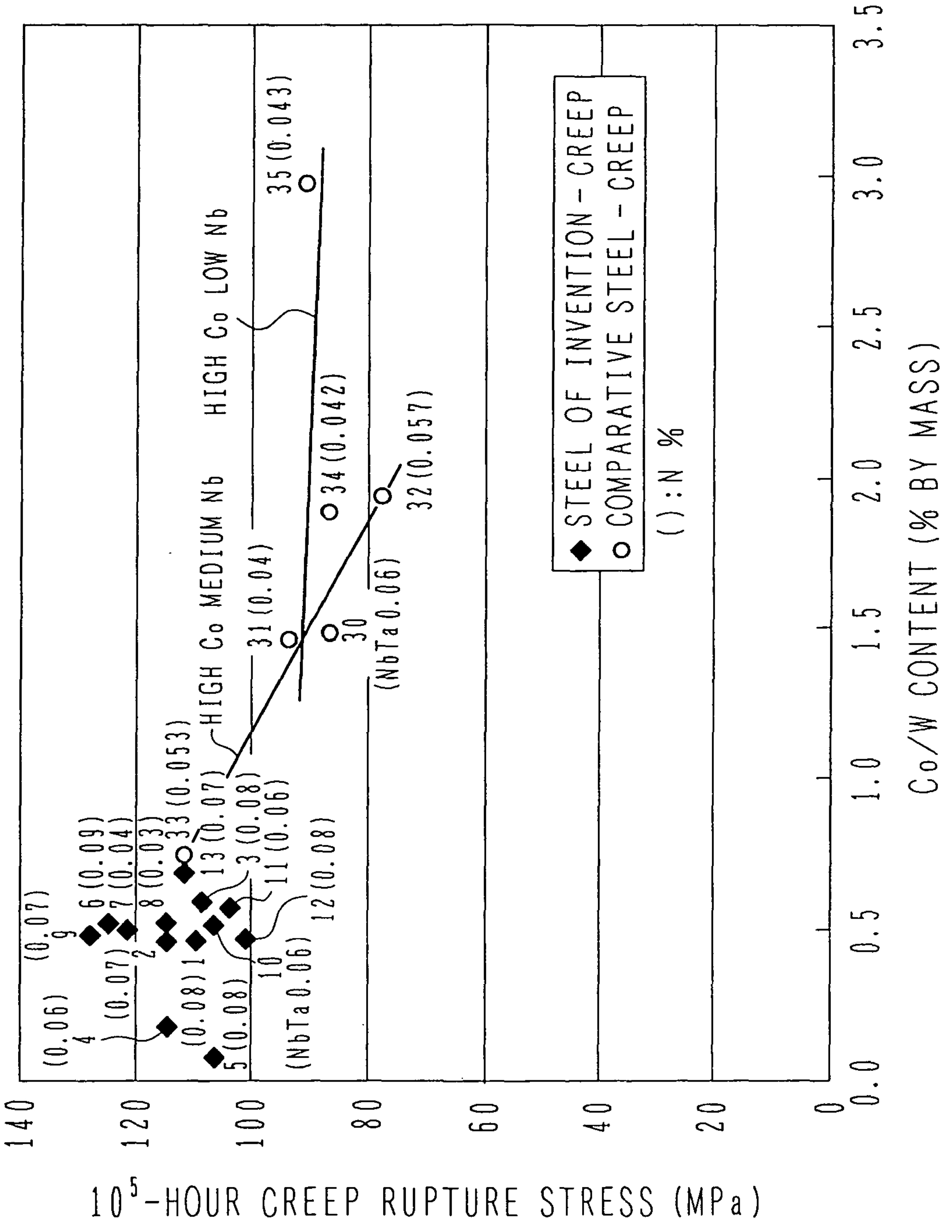

10^5-HOUR CREEP RUPTURE STRESS (MPa)
140
120
100
80
60
40
20
0
Co/W CONTENT (% BY MASS)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
STEEL OF INVENTION - CREEP
COMPARATIVE STEEL - CREEP
( ):N %
HIGH Co MEDIUM Nb
HIGH Co LOW Nb
(0.06) 4
(0.07) 9
(0.07)
(0.07) 2
(0.08) 1
5 (0.08)
6 (0.09)
7 (0.04)
8 (0.03)
33 (0.053)
13 (0.07)
3 (0.08)
11 (0.06)
12 (0.08)
10 (NbTa 0.06)
31 (0.04)
30 (NbTa 0.06)
34 (0.042)
32 (0.057)
35 (0.043)

FIG.8

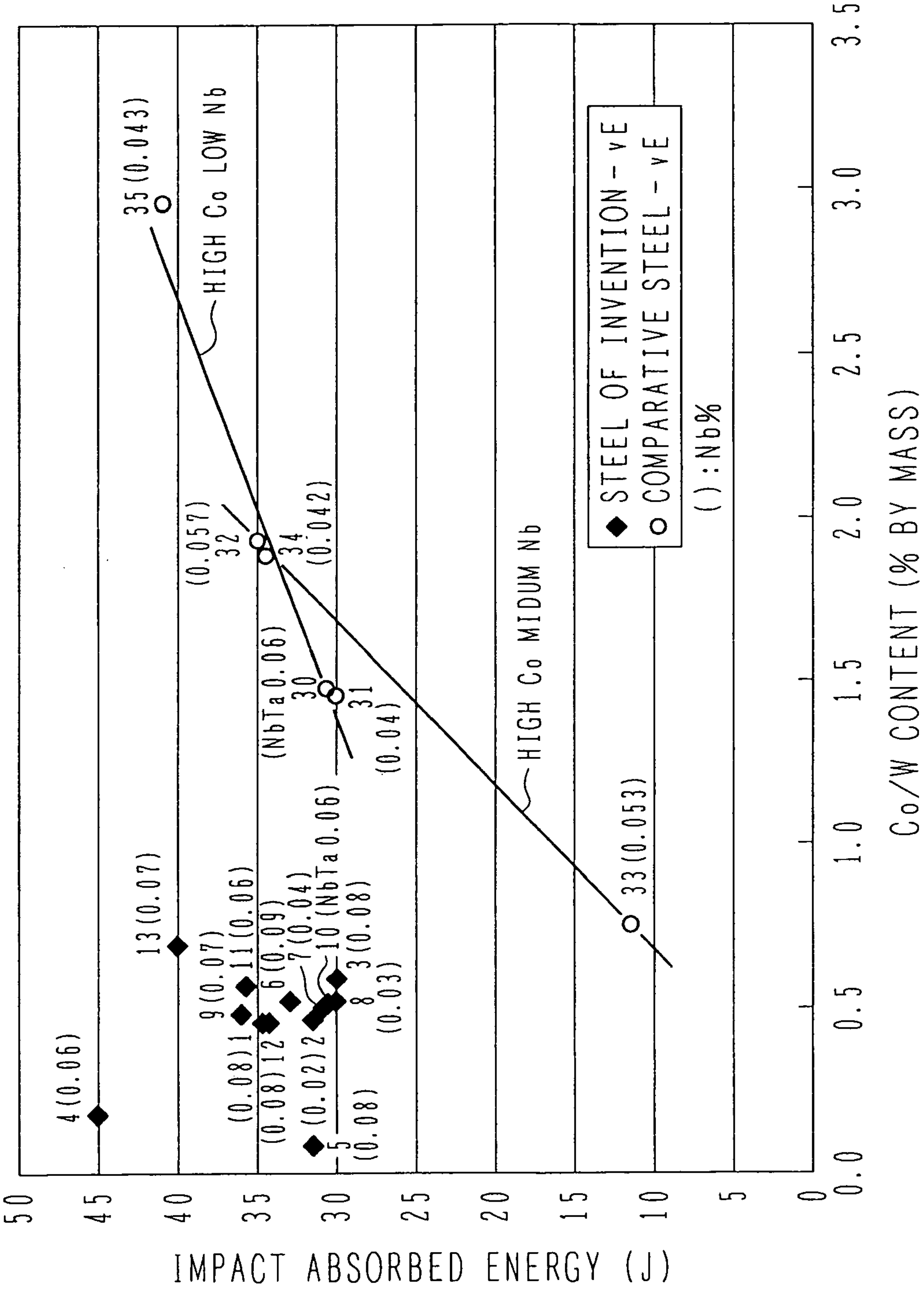

IMPACT ABSORBED ENERGY (J)
50
45
40
35
30
25
20
15
10
5
0
Co/W CONTENT (% BY MASS)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
◆ STEEL OF INVENTION - vE
○ COMPARATIVE STEEL - vE
( ):Nb%
HIGH Co LOW Nb
HIGH Co MIDUM Nb
35(0.043)
(0.057) 32
34 (0.042)
(NbTa0.06) 30
31 (0.04)
33(0.053)
4(0.06)
13(0.07)
9(0.07)
11(0.06)
(0.08)1
(0.08)12
6(0.09)
7(0.04)
(0.02)2
10(NbTa0.06)
3(0.08)
8 (0.03)
5 (0.08)

FIG. 9

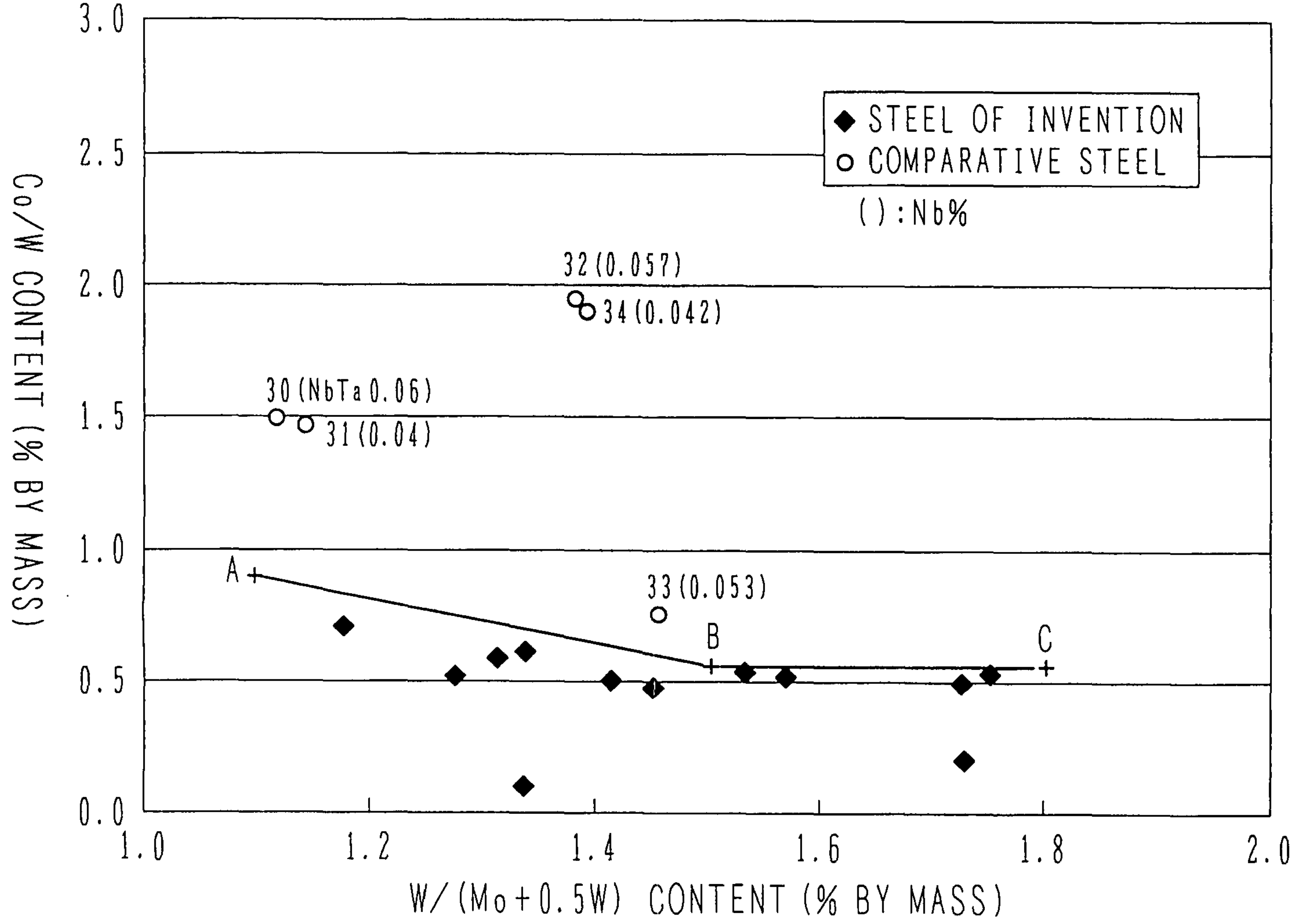

◆ STEEL OF INVENTION
○ COMPARATIVE STEEL
( ):Nb%
32(0.057)
34(0.042)
30(NbTa0.06)
31(0.04)
33(0.053)
A
B
C
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.0
1.2
1.4
1.6
1.8
2.0
Co/W CONTENT (% BY MASS)
W/(Mo+0.5W) CONTENT (% BY MASS)

FIG.10

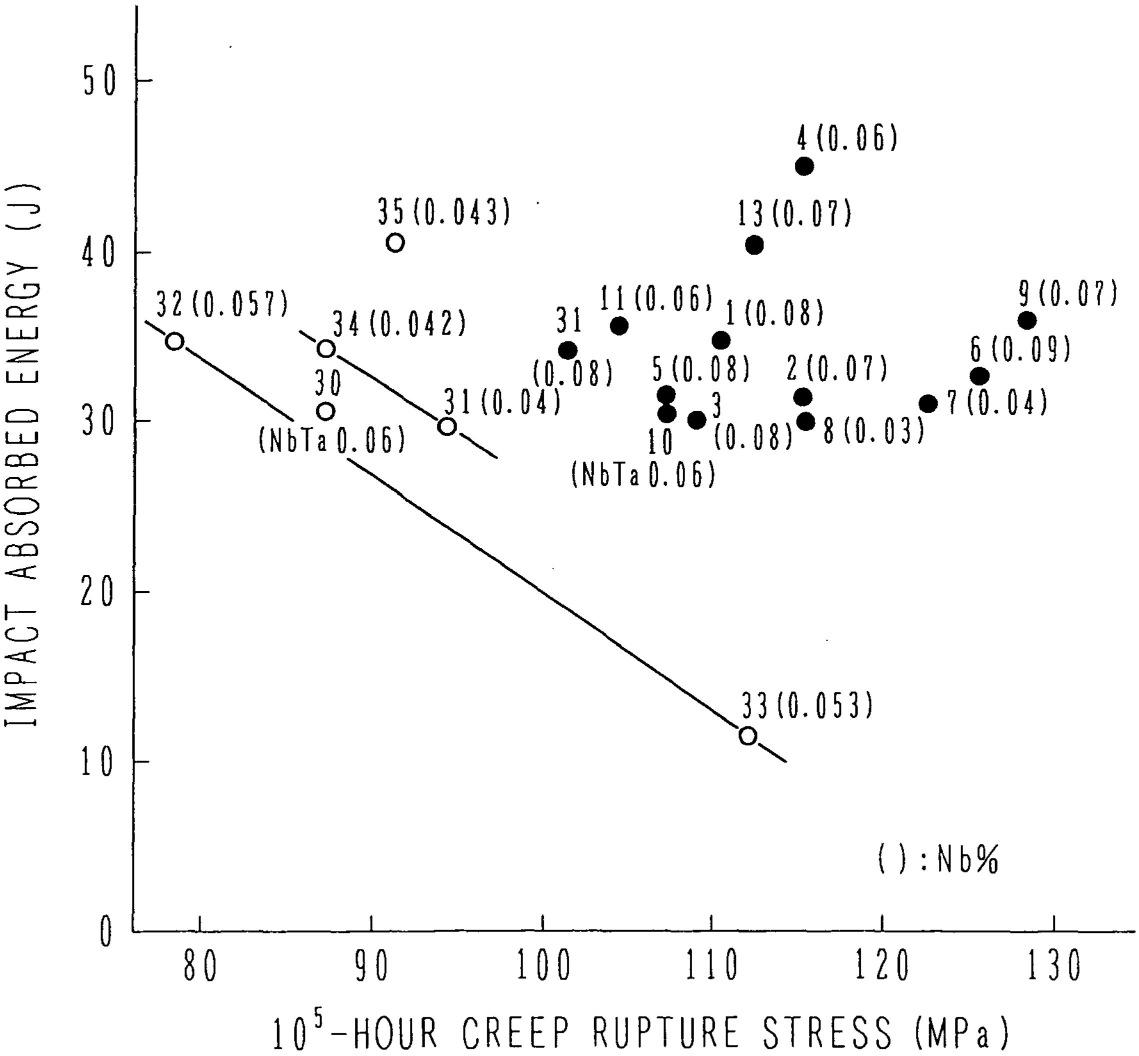

IMPACT ABSORBED ENERGY (J)
0
10
20
30
40
50
80
90
100
110
120
130
10⁵-HOUR CREEP RUPTURE STRESS (MPa)
4(0.06)
13(0.07)
35(0.043)
32(0.057)
34(0.042)
30
(NbTa 0.06)
31(0.04)
31
(0.08)
11(0.06)
1(0.08)
5(0.08)
10
(NbTa 0.06)
3
(0.08)
2(0.07)
8(0.03)
7(0.04)
6(0.09)
9(0.07)
33(0.053)
( ):Nb%

FIG. 11

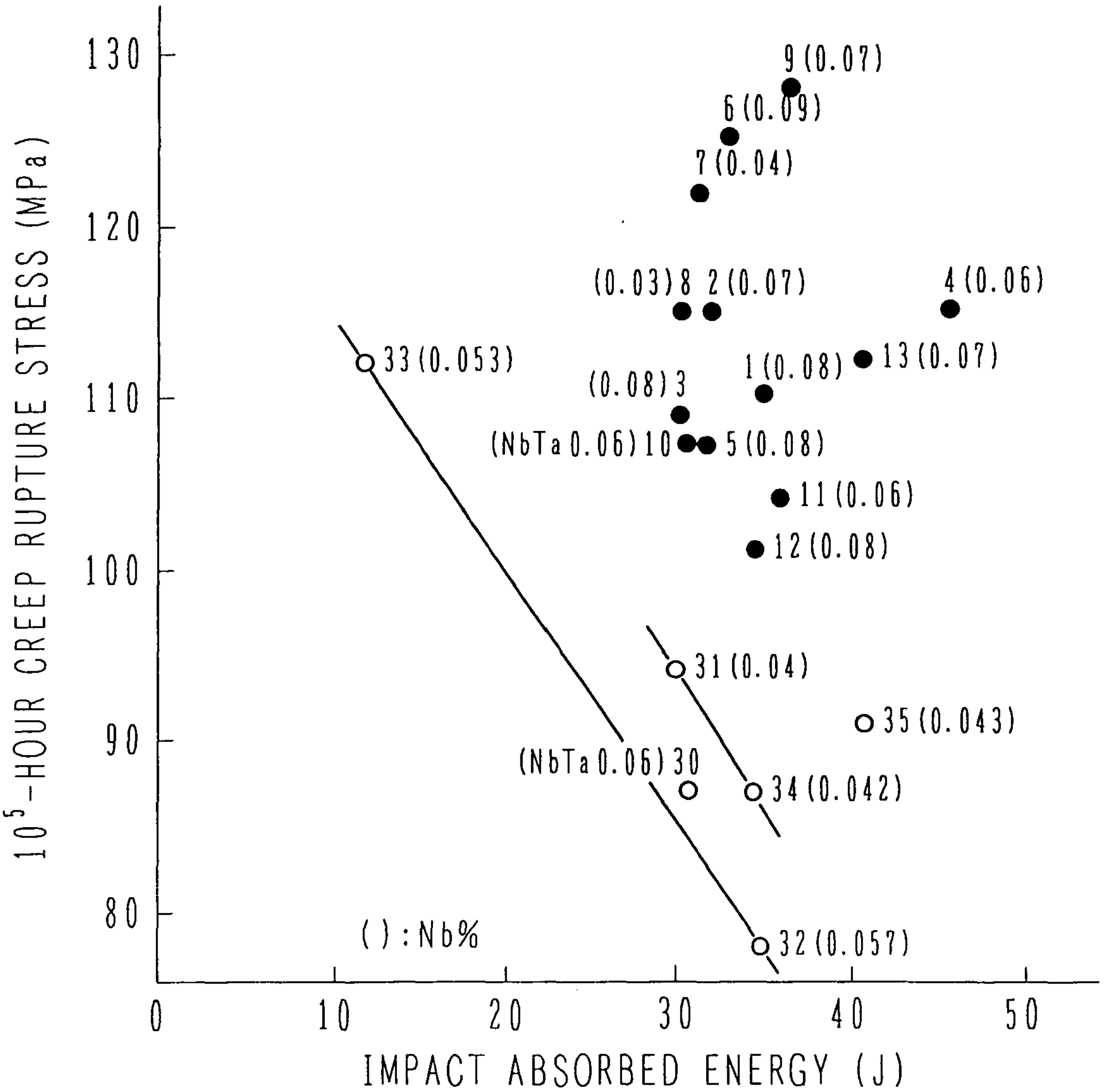

10^5-HOUR CREEP RUPTURE STRESS (MPa)
130
120
110
100
90
80
0
10
20
30
40
50
IMPACT ABSORBED ENERGY (J)
9 (0.07)
6 (0.09)
7 (0.04)
(0.03) 8
2 (0.07)
4 (0.06)
33 (0.053)
1 (0.08)
13 (0.07)
(0.08) 3
(NbTa 0.06) 10
5 (0.08)
11 (0.06)
12 (0.08)
31 (0.04)
35 (0.043)
(NbTa 0.06) 30
34 (0.042)
( ) : Nb%
32 (0.057)

FIG.12A

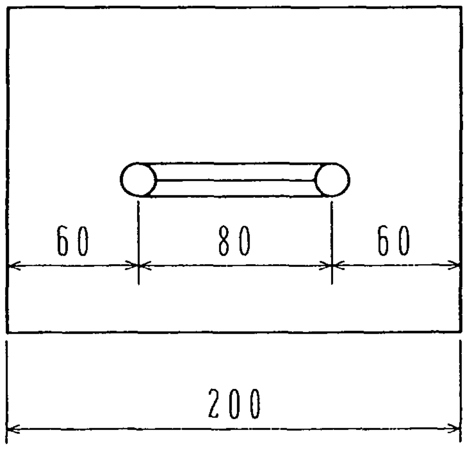


FIG.12B

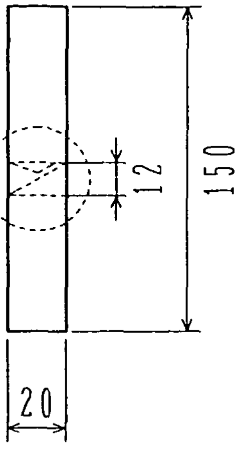


FIG.12C

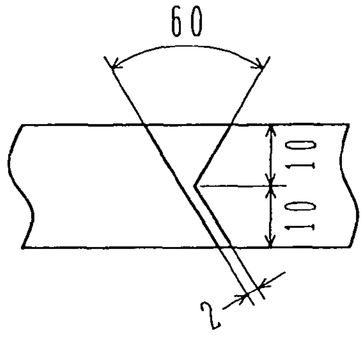


FIG.13

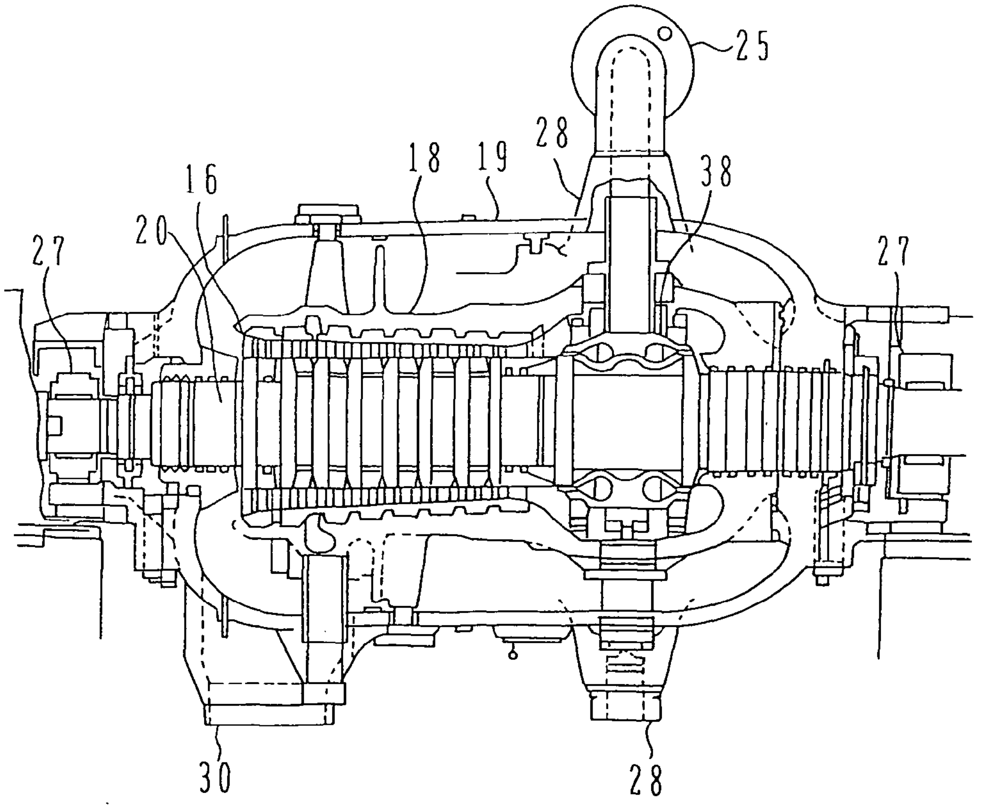


FIG. 14

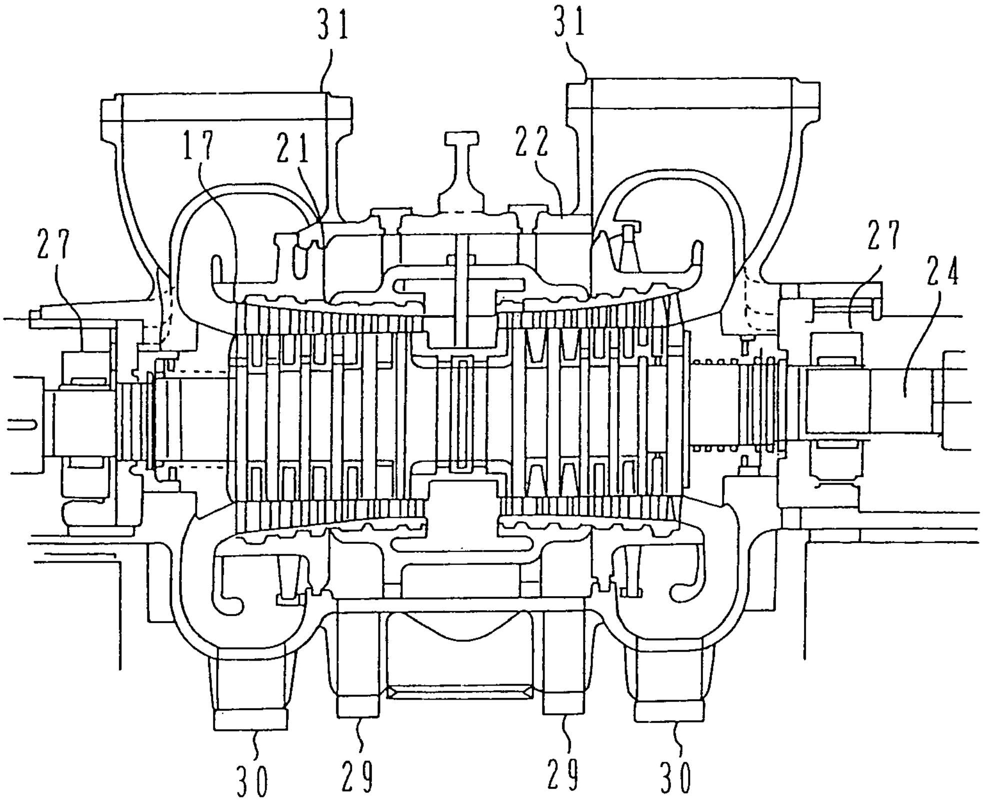


FIG.15

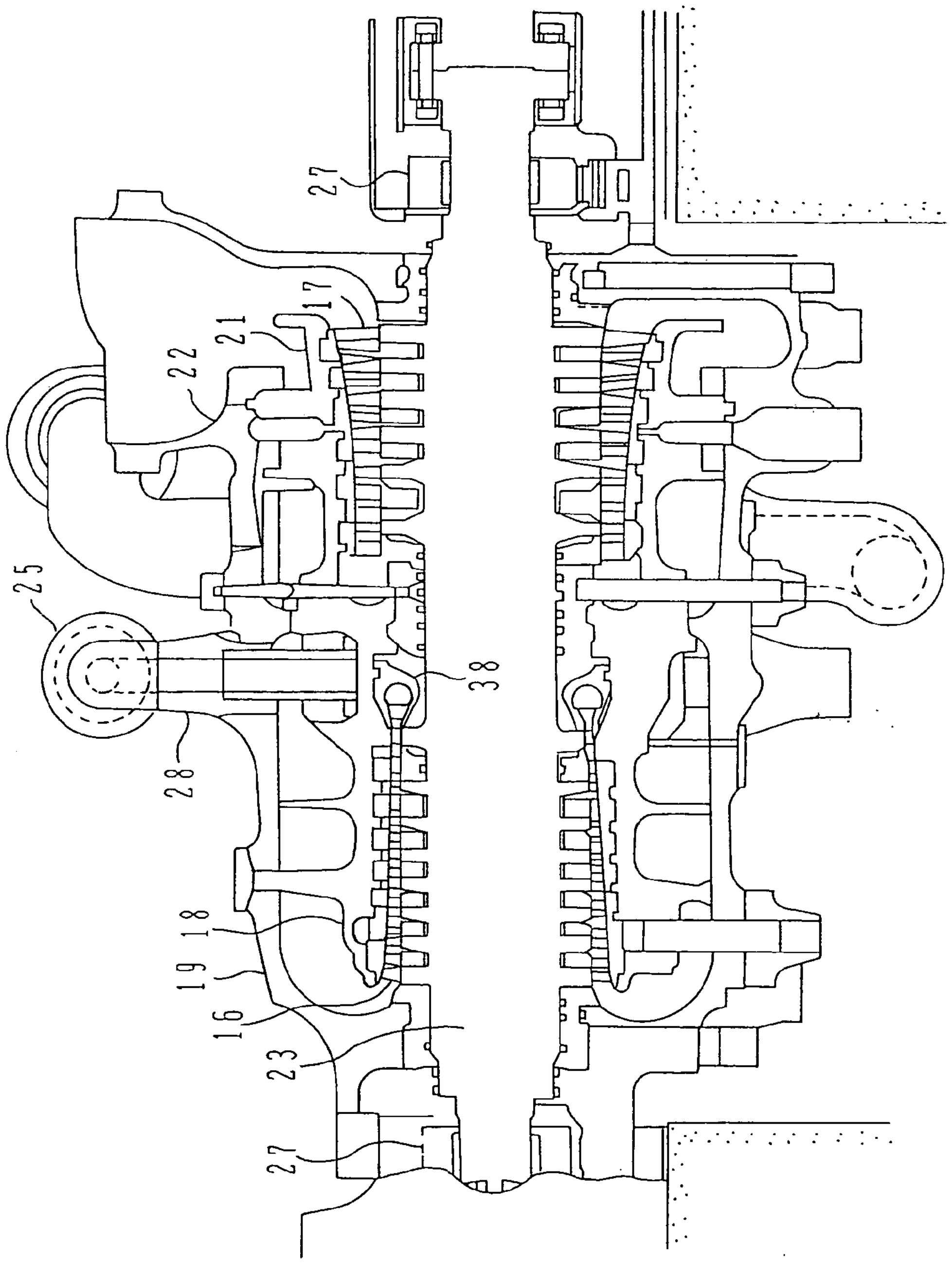
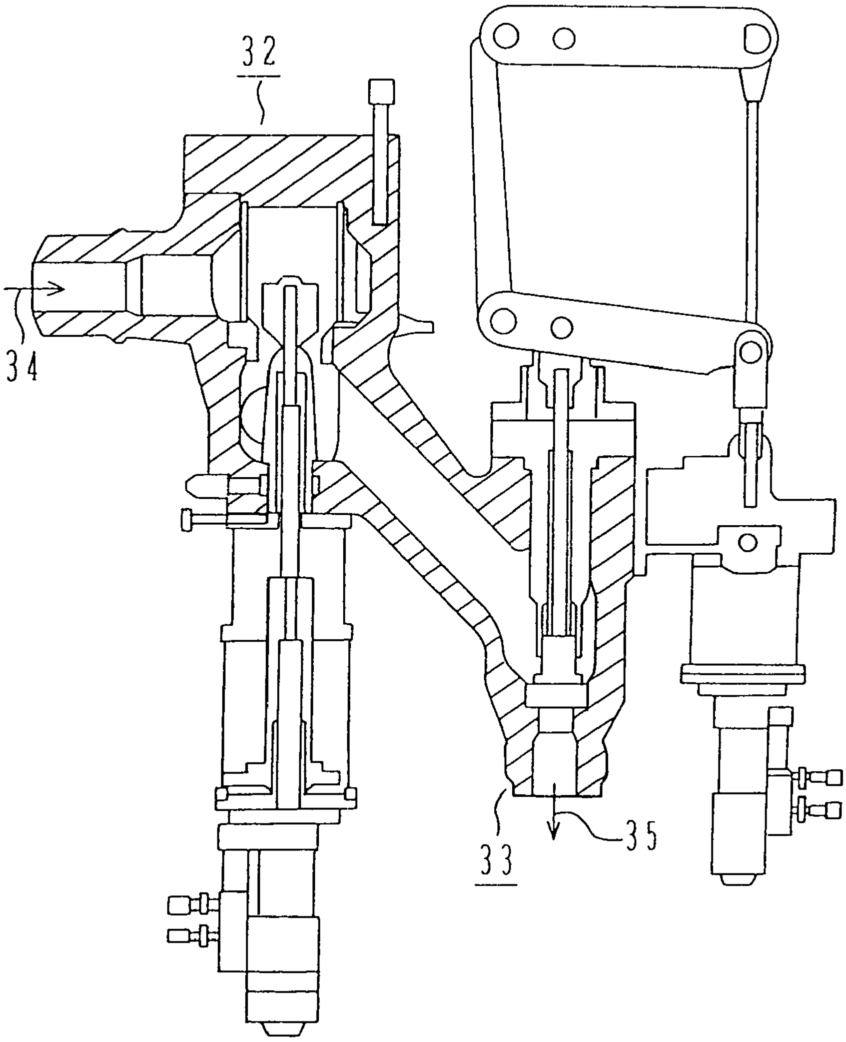


FIG. 16



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 06 02 0264

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	JP 09 291308 A (NIPPON STEEL CORP) 11 November 1997 (1997-11-11) abstract	1-5	INV. C22C38/00
Y	* examples B,G; table 1 *	6-17	

X	JP 05 263196 A (NIPPON STEEL CORP) 12 October 1993 (1993-10-12) abstract	1-5	
Y	* example 2; table 1 *	6-17	

X	JP 07 286246 A (NIPPON STEEL CORP; FUJITA TOSHIO) 31 October 1995 (1995-10-31) abstract	1-5	
Y	* examples 6,8; tables 1,2 *	6-17	

X	JP 07 286247 A (NIPPON STEEL CORP; FUJITA TOSHIO) 31 October 1995 (1995-10-31) abstract	1-5	
Y	* examples 6,9; tables 1,2 *	6-17	

X	JP 2001 192781 A (SUMITOMO METAL IND) 17 July 2001 (2001-07-17) abstract	1-5	TECHNICAL FIELDS SEARCHED (IPC)
Y	* example H; tables 1,3 *	6-17	C22C

Y	EP 0 767 250 A2 (HITACHI LTD [JP]) 9 April 1997 (1997-04-09) * page 8, line 46 - line 56 * * claims 17-42 *	6-17	

A	JP 2001 152293 A (SUMITOMO METAL IND) 5 June 2001 (2001-06-05) * examples 1-18; tables 1,2 *	1-5	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	13 December 2006	Gavriliu, Alexandru

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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& : member of the same patent family, corresponding document

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 06 02 0264

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The members are as contained in the European Patent Office EDP file on
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13-12-2006

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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JP 5263196 A	12-10-1993	NONE	
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EP 0767250 A2	09-04-1997	JP 9059747 A US 5961284 A	04-03-1997 05-10-1999
JP 2001152293 A	05-06-2001	NONE	

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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- JP 7118812 A **[0003]**
- JP 62180044 A **[0003]**
- JP 2290950 A **[0003]**
- JP 4371551 A **[0003]**
- JP 9059747 A **[0003]**