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Patent- und Rechtsanwälte

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(54) **Ni-based alloy for a casting part of a steam turbine with excellent high temperature strength, castability and weldability**

(57) A Ni-based alloy for a casting part of a steam turbine having excellent high temperature strength, castability and weldability includes, in percentage by mass, 0.01 to 0.15 of C, 18 to 28 of Cr, 10 to 15 of Co,

8 to 12 of Mo, 1.5 to 2 of Al, 0.1 to 3 of Ti, 0.001 to 0.006 of B, 0.1 to 0.7 of Ta, and the balance of Ni plus unavoidable impurities.

EP 2 206 795 A2

Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2008-328459 filed on December 24, 2008; the entire contents which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

[0002] The present invention relates to a material making a casting part of a steam turbine in which a high temperature steam as a working fluid is flowed. Particularly, the present invention relates to a Ni-based alloy of a casting part of the steam turbine with excellent high temperature strength, castability and weldability, and a turbine casing of the steam turbine, a valve casing of the steam turbine, a nozzle box of the steam turbine and a pipe of the steam turbine which are made of the Ni-based alloy for the casting part of the steam turbine.

2. DESCRIPTION OF THE RELATED ART

[0003] In a thermal power plant including a steam turbine, an attention is paid to a CO₂ gas emission reduction technique in view of global environmental protection, and the high efficiency of generation of electricity is required.

[0004] In order to develop the efficiency of power generation of a steam turbine, it is effective that the temperature of the steam to be employed in the steam turbine is increased. In a recent thermal power plant with a steam turbine, the steam temperature is increased to 600°C or more. In a future thermal power plant with a steam turbine, the steam temperature is likely to be increased up to 650°C or 700°C.

[0005] The turbine casings, valve casings, nozzle boxes, pipes and the like of the steam turbine, which are to be exposed to a high temperature steam, may cause large stresses therein as the temperature of the steam flowing around the turbine casings, valve casings, nozzle boxes, pipes and the like of the steam turbine is increased. In this point of view, these parts of the steam turbine are required to resist against such a high temperature condition and such a high stress condition and thus, to be made of respective materials with excellent strength, ductility and toughness within a temperature range of room temperature through high temperature.

[0006] Particularly, when the steam temperature exceeds 700°C, a Ni-based alloy is considered to be used because a conventional Fe-based material cannot have enough high temperature strength (refer to Reference 1).

[0007] Since the Ni-based alloy has its excellent high temperature strength and high corrosion resistance, the Ni-based alloy would be employed mainly for jet engines and gas turbines. As the Ni-based alloy may be typically exemplified Inconel Alloy 617 (made by Special Metals Corporation and Inconel Alloy 706 (made by Special Metals Corporation).

[0008] The mechanism of enhancement in high temperature strength of the Ni-based alloy is originated from a precipitated phase such as a gamma prime phase (Ni₃(Al, Ti) and/or gamma double prime phase in the matrix phase of the Ni-based alloy by adding Al and Ti to the Ni-based alloy. In Inconel Alloy 706, both of the gamma prime phase and the gamma double prime phase are precipitated to develop the high temperature strength thereof.

[0009] In Inconel Alloy 617 or the like, on the other hand, Co and Mo are solid-solved (i.e., the use of solute strengthening) in the matrix phase of the Ni-based alloy so as to develop the high temperature strength thereof.

[Reference 1] JP-A 07-150277 (KOKAI)

[0010] As described above, although the Ni-based alloy is considered to be applied as a turbine rotor material of a steam turbine within a temperature range of more than 700°C, the high temperature strength is not enough for the Ni-based alloy to be employed under such a high temperature condition. Moreover, it is required that the high temperature strength of the Ni-based alloy is developed by the modification of the composition of the Ni-based alloy while the castability and weldability of the Ni-based alloy are maintained.

BRIEF SUMMARY OF THE INVENTION

[0011] It is an object of the present invention to provide a Ni-based alloy of a casting part of a steam turbine with excellent high temperature strength, castability and weldability, and a turbine casing of the steam turbine, a valve casing of the steam turbine, a nozzle box of the steam turbine and a pipe of the steam turbine which are made of the Ni-based alloy for the casting part of the steam turbine.

[0012] In order to achieve the object of the present invention, an aspect of the present invention relates to a Ni-based

alloy for a casting part of a steam turbine having excellent high temperature strength, castability and weldability, including, in percentage by mass, 0.01 to 0.15 of C, 18 to 28 of Cr, 10 to 15 of Co, 8 to 12 of Mo, 1.5 to 2 of Al, 0.1 to 3 of Ti, 0.001 to 0.006 of B, 0.1 to 0.7 of Ta, and the balance of Ni plus unavoidable impurities.

[0013] Another aspect of the present invention relates to a Ni-based alloy for a casting part of a steam turbine having excellent high temperature strength, castability and weldability, including, in percentage by mass, 0.01 to 0.15 of C, 18 to 28 of Cr, 10 to 15 of Co, 8 to 12 of Mo, 1.5 to 2 of Al, 0.1 to 3 of Ti, 0.001 to 0.006 of B, 0.1 to 0.4 of Nb, and the balance of Ni plus unavoidable impurities.

[0014] Still another aspect of the present invention relates to a Ni-based alloy for a casting part of a steam turbine having excellent high temperature strength, castability and weldability, including, in percentage by mass, 0.01 to 0.15 of C, 18 to 28 of Cr, 10 to 15 of Co, 8 to 12 of Mo, 1.5 to 2 of Al, 0.1 to 3 of Ti, 0.001 to 0.006 of B, 0.1 to 0.7 of Ta + 2Nb (Ta:Nb in mole ratio is 1:2), and the balance of Ni plus unavoidable impurities.

[0015] A further aspect of the present invention relates to a turbine casing of a steam turbine, including at least a portion made of any one of the Ni-based alloys as described above through casting.

[0016] A still further aspect of the present invention relates to a valve casing of a steam turbine, including at least a portion made of any one of the Ni-based alloys as described above through casting.

[0017] Another aspect of the present invention relates to a nozzle box of a steam turbine, including at least a portion made of any one of the Ni-based alloys as described above through casting.

[0018] Still another aspect of the present invention relates to a pipe of a steam turbine, including at least a portion made of any one of the Ni-based alloys as described above through casting.

[0019] According to the Ni-based alloy of a casting part of a steam turbine with excellent high temperature strength, castability and weldability, and the turbine casing of the steam turbine, the valve casing of the steam turbine, the nozzle box for the steam turbine and the pipe for the steam turbine which are made of the Ni-based alloy for the casting part of the steam turbine as set forth in the present invention, the high temperature strength, the castability and the weldability in the Ni-based alloy and these parts of the present invention can be enhanced in comparison with the conventional ones.

BEST MODE FOR IMPLEMENTING THE INVENTION

[0020] Hereinafter, the present invention will be described in detail with reference to the drawings.

[0021] A Ni-based alloy of a casting part of a steam turbine with excellent high temperature strength, castability and weldability according to an embodiment of the present invention has a composition as described below. Here, the denomination "%" means "% by mass" unless otherwise specified.

[0022] (M1) C: 0.01 to 0.15%, Cr: 18 to 28%, Co: 10 to 15%, Mo: 8 to 12%, Al: 1.5 to 2%, Ti: 0.1 to 3%, B: 0.001 to 0.006%, Ta: 0.1 to 0.7%, and the balance of Ni plus unavoidable impurities.

[0023] (M2) C: 0.01 to 0.15%, Cr: 18 to 28%, Co: 10 to 15%, Mo: 8 to 12%, Al: 1.5 to 2%, Ti: 0.1 to 3%, B: 0.001 to 0.006%, Nb: 0.1 to 0.4%, and the balance of Ni plus unavoidable impurities.

[0024] (M3) C: 0.01 to 0.15%, Cr: 18 to 28%, Co: 10 to 15%, Mo: 8 to 12%, Al: 1.5 to 2%, Ti: 0.1 to 3%, B: 0.001 to 0.006%, Ta + 2Nb: 0.1 to 0.7%, and the balance of Ni plus unavoidable impurities. Here, the term "Ta + 2Nb" means that Ta:Nb in mole ratio is 1:2.

[0025] With the unavoidable impurities of the Ni-based alloy numbered as (M1) to (M3), it is desired that the content of Si is set to 0.1% or less and the content of Mn is set to 0.1% or less. As the unavoidable impurities can be exemplified Cu, Fe and S in addition to Si and Mn.

[0026] The Ni-based alloy having such a composition as described above is preferable for a material making a casting part of a steam turbine which is operated within a temperature range of 680°C to 750°C. As the casting part of the steam turbine may be exemplified a turbine casing of the steam turbine, a valve casing of the steam turbine, a nozzle box of the steam turbine and a pipe of the steam turbine.

[0027] Here, the turbine casing is constructed such that a turbine rotor with turbine rotor blades implanted therein is penetrated through the turbine casing and nozzles for introducing steams into the turbine casing are arranged in the interior surface of the turbine casing, thereby constituting a turbine cylinder. The valve casing is a casing for a valve functioning as a steam valve which controls the flow rate of a high-temperature and pressure steam to be supplied to a steam turbine and/or to shut off the flow of the steam. As the casing valve, a casing for a valve to be employed under the condition that a steam of 680 to 750°C is flowed may be exemplified. The nozzle box is a ring-shaped steam flow path, which is provided around the turbine rotor, for introducing the high-temperature and pressure steam supplied in the steam turbine into the first section of the steam turbine with first nozzles and first turbine rotor blades. The pipe is a main steam pipe for introducing the steam from a boiler into a high pressure turbine or a high temperature-reheat steam pipe. The turbine casing, the valve casing, the nozzle box and the pipe are provided under the environment where these parts are exposed to a high-temperature and pressure steam.

[0028] The Ni-based alloy may be applied for every portion of the casting part of the steam turbine or a portion of the casting part thereof. The casting parts of the steam turbine arranged over the high pressure steam turbine are likely to

be disposed under the high-temperature and pressure atmosphere.

Alternatively, the casting parts of the steam turbine arranged in the area from the high pressure steam turbine bridging to a part of the medium pressure turbine are also likely to be disposed under the high-temperature and pressure atmosphere. The casting part of the steam turbine to be disposed under the high-temperature and pressure atmosphere is not limited to the above-exemplified ones. In the present specification, the phrase of "the casting part of the steam turbine to be disposed under the high-temperature and pressure atmosphere" means a casting part of the steam turbine disposed and exposed to the temperature atmosphere within a temperature range of 680°C to 750°C.

[0029] The Ni-based alloy as described above has a high temperature strength, castability and weldability superior than those of a conventional Ni-based alloy. Therefore, if such a casting part of a steam turbine as the turbine casing, the valve casing, the nozzle box and the pipe may be made of the Ni-based alloy of this embodiment according to the present invention, the casting part can have a higher reliability under the high temperature atmosphere. Namely, the turbine casing, the valve casing, the nozzle box and the pipe with the respective high reliabilities under the high temperature atmosphere can be manufactured.

[0030] Then, the reason for defining the composition range of the Ni-based alloy according to the present invention will be described.

(1) C (Carbon)

[0031] Carbon (C) is effective as a constituent element of $M_{23}C_6$ carbide functioning as reinforcing phase. Particularly, the precipitation of the $M_{23}C_6$ carbide during the operation of the steam turbine is one of main factors for maintaining the creep strength of an alloy (i.e., the Ni-based alloy) under a high temperature atmosphere of 650°C or more. Alternatively, carbon has an effect of ensuring the fluidity of a hot melt during casting. When the carbon content is set less than 0.01%, the mechanical strength (hereinafter, often means a high temperature strength) of the Ni-based alloy may be reduced because the carbide cannot be sufficiently precipitated, and the fluidity of the hot melt of the Ni-based alloy during casting is reduced conspicuously. On the other hand, when the carbon content is set more than 0.15%, the composition segregation of the hot melt of the Ni-based alloy at the production of a large ingot of the Ni-based alloy is inclined to be increased and the creation of M_6C carbide as brittle phase is promoted. In this point of view, the carbon content is set within a range of 0.01 to 0.15%.

(2) Cr (Chromium)

[0032] Chromium (Cr) is inevitable element for developing the oxidation resistance, the corrosion resistance and the mechanical strength of the Ni-based alloy, and inevitable as a constituent element of $M_{23}C_6$ carbide. Particularly, the precipitation of the $M_{23}C_6$ carbide during the operation of the steam turbine is one of main factors for maintaining the creep strength of an alloy (i.e., the Ni-based alloy) under a high temperature atmosphere of 650°C or more. Alternatively, chromium has an effect of enhancing the oxidation resistance of the Ni-based alloy under a high temperature steam atmosphere. When the chromium content is set less than 18%, the oxidation resistance of the Ni-based alloy may be reduced. On the other hand, when the chromium content is set more than 28%, the precipitation of $M_{23}C_6$ carbide is remarkably promoted so as to increase the inclination of the coarsening of the precipitated $M_{23}C_6$ carbide. In this point of view, the chromium content is set within a range of 18 to 28%.

(3) Co (Cobalt)

[0033] Cobalt (Co) is solid-solved into the matrix phase of the Ni-based alloy to enhance the mechanical strength of the matrix phase thereof. However, when the cobalt content is set more than 15%, such intermetallic compound phases as lowering the mechanical strength of the Ni-based alloy are generated so that the mechanical strength of the Ni-based alloy is reduced. On the other hand, when the cobalt content is set less than 10%, the processability (castability) of the Ni-based alloy is reduced and the mechanical strength of the Ni-based alloy is also reduced. In this point of view, the carbon content is set within a range of 10 to 15%.

(4) Mo (Molybdenum)

[0034] Molybdenum (Mo) is solid-solved into the matrix phase of the Ni-based alloy to enhance the mechanical strength of the matrix phase thereof. Moreover, a part of the constituent elements of the $M_{23}C_6$ carbide is substituted with Mo elements to enhance the stability of the $M_{23}C_6$ carbide. When the Molybdenum content is set less than 8%, the above-described effect/function cannot be exhibited. When the Molybdenum content is set more than 12%, the composition segregation of the hot melt of the Ni-based alloy at the production of a large ingot of the Ni-based alloy is inclined to be increased and the creation of M_6C carbide as brittle phase is promoted. In this point of view, the molybdenum content

is set within a range of 8 to 12%.

(5) Al (Aluminum)

[0035] Aluminum (Al) generates a γ' phase (gamma prime phase: Ni_3Al) with nickel so as to develop the mechanical strength of the Ni-based alloy through the precipitation of the γ' phase. When the aluminum content is set less than 1.5%, the mechanical strength and the processability (castability) of the Ni-based alloy are not developed in comparison with a conventional steel. When the aluminum content is set more than 2%, the mechanical strength of the Ni-based alloy is developed, but the processability (castability) of the Ni-based alloy is reduced. In this point of view, the aluminum content is set within a range of 1.5 to 2%.

(6) Ti (Titanium)

[0036] Titanium (Ti) generates a γ' phase (gamma prime phase: Ni_3Al) with nickel in the same manner as aluminum so as to develop the mechanical strength of the Ni-based alloy. When the titanium content is set less than 0.1%, the hot workability of the Ni-based alloy is deteriorated. When the titanium content is set more than 3%, the notch sensitivity of the Ni-based alloy is increased. In this point of view, the titanium content is set within a range of 0.1 to 3%.

(7) B (Boron)

[0037] Boron (B) is solid-solved into the matrix phase of the Ni-based alloy to enhance the mechanical strength of the matrix phase thereof. When the boron content is set less than 0.001%, the mechanical strength of the matrix phase thereof cannot be developed. When the boron content is set more than 0.006%, grain boundary embrittlement may be caused in the Ni-based alloy. In this point of view, the boron content is set within a range of 0.001 to 0.006%.

(8) Ta (Tantalum)

[0038] Tantalum (Ta) stabilizes the precipitation strengthening of the γ' phase (gamma prime phase ($\text{Ni}_3(\text{Al}, \text{Ti})$)). When the tantalum content is set less than 0.1%, the stability of the precipitation strengthening cannot be enhanced in comparison with a conventional steel. When the tantalum content is set more than 0.7%, the production cost of the Ni-based alloy is increased so that the economic efficiency is deteriorated. In this point of view, the tantalum content is set within a range of 0.1 to 0.7%.

(9) Nb (Niobium)

[0039] Niobium (Nb) is solid-solved into the γ' phase (gamma prime phase ($\text{Ni}_3(\text{Al}, \text{Ti})$)) so as to stabilize the precipitation strengthening thereof. When the niobium content is set less than 0.1%, the stability of the precipitation strengthening cannot be enhanced in comparison with a conventional steel. When the niobium content is set more than 0.4%, the mechanical strength of the Ni-based alloy is developed, but the processability (castability) is reduced. In this point of view, the niobium content is set within a range of 0.1 to 0.4%.

[0040] With Ta and Nb, the precipitation strengthening of the γ' phase (gamma prime phase ($\text{Ni}_3(\text{Al}, \text{Ti})$)) can be developed by setting the total content represented by the expression ($\text{Ta} + 2\text{Nb}$) within a range of 0.1 to 0.7%. When the total content of ($\text{Ta} + 2\text{Nb}$) is set less than 0.1%, the precipitation strengthening may not be developed sufficiently in comparison with a conventional steel. When the total content of ($\text{Ta} + 2\text{Nb}$) is set more than 0.7%, the mechanical strength of the Ni-based alloy is developed, but the processability (castability) of the Ni-based alloy may be reduced. The tantalum content and the niobium content are set at least to 0.01% or more, respectively.

[0041] Since the specific gravity of niobium is about half as large as the specific gravity of tantalum (specific gravity of tantalum: 16.6, specific gravity of niobium: 8.57), the total solid solubility into the matrix phase of the Ni-based alloy can be increased by adding tantalum and niobium in combination into the matrix phase thereof in comparison with the addition of tantalum. Moreover, since tantalum is a strategic substance, it is difficult to obtain it stably. On the other hand, since the reserve of niobium is about one hundred times as much as the reserve of tantalum, niobium can be stably supplied. Since the melting point of tantalum is higher than the melting point of niobium (melting point of tantalum: about 3000°C, melting point of niobium: about 2470°C), the γ' phase is strengthened under a higher temperature condition. In addition, the oxidation resistance of tantalum is superior than the oxidation resistance of niobium. (10) Si (Silicon), Mn (Manganese), Cu (Copper), Fe (iron) and S (Sulfur)

[0042] With the Ni-based alloy according to the present invention, silicon (Si), manganese (Mn), copper (Cu), iron (Fe) and sulfur (S) are classified as unavoidable impurities. It is desired that the remaining contents of these impurities are reduced to zero % as possible. It is desired that the remaining contents of at least silicon (Si) and manganese (Mn)

among these impurities are set to 0.1% or less, respectively.

[0043] In a plain carbon steel, silicon (Si) is added thereto for compensating the poor corrosion resistance thereof. However, since the Ni-based alloy contains a relatively large amount of chromium (Cr) to ensure the corrosion resistance of the Ni-based alloy, the remaining content of silicon (Si) in the Ni-based alloy is set to 0.1% or less and then, desirably reduced to zero % as possible.

[0044] In a plain carbon steel, manganese (Mn) constitutes manganese sulfide (MnS) with sulfur (S) so as to suppress the brittleness of the Ni-based alloy because sulfur (S) may cause the brittleness for the plain carbon steel. However, since the remaining content of sulfur (S) in the Ni-based alloy is extremely low, it is not required to add manganese (Mn) into the Ni-based alloy. In this point of view, the remaining content of manganese (Mn) is set to 0.1% or less and then, desirably reduced to zero % as possible.

[0045] The Ni-based alloy for a casting part of a steam turbine according to the present invention, which is used for the turbine casing, the valve casing and the nozzle box, can be produced as follows: First of all, the composition of the Ni-based alloy is melted by means of vacuum induction melting (VIM) and the thus obtained hot melt is injected into a molding box to form an ingot. Then, the ingot is treated by means of solution treatment.

[0046] In the manufacture of the pipe made of the Ni-based alloy of a casting part of a steam turbine according to the present invention, the composition of the Ni-based alloy is melted by means of vacuum induction melting (VIM) and the thus obtained hot melt is injected into a cylindrical molding box under the condition that the cylindrical molding box is rotated at high rotation speed. In this case, since the hot melt is pressurized by the centrifugal force originated from the rotation of the cylindrical molding box, the thus obtained ingot is formed in a predetermined pipe shape, and then, treated by means of solution treatment. In this way, the pipe of the steam turbine can be manufactured, which is called as centrifugal casting method.

[0047] The solution treatment is preferably conducted for 4 to 15 hours within a temperature range of 1100 to 1200°C. The solution treatment is conducted in order to solid-solve the γ' precipitated phase uniformly. When the temperature in the solution treatment is set less than 1100°C, the solid-solution cannot be conducted sufficiently. When the temperature in the solution treatment is set more than 1200°C, the strength of the Ni-based alloy is reduced due to the coarsening of crystal grains thereof.

[0048] The turbine casing, the valve casing and the nozzle box as casting parts according to the present invention may be manufactured as follows: First of all, the composition of the Ni-based alloy for the casting part of the steam turbine according to the present invention is melted by means of vacuum induction melting (VIM), and the thus obtained hot melt is injected into a corresponding molding box and then, casted under atmosphere. The thus obtained ingot is treated by means of solution treatment.

[0049] The turbine casing, the valve casing and the nozzle box as casting parts according to the present invention may be also manufactured as follows: First of all, the composition of the Ni-based alloy for the casting part of the steam turbine according to the present invention is melted by means of electric furnace (EF), and decarburized by means of argon-oxygen decarburization (AOD). The thus obtained hot melt is injected into a corresponding molding box and then, casted under atmosphere. The thus obtained ingot is treated by means of solution treatment.

[0050] The pipe as a casting part according to the present invention may be manufactured as follows: First of all, the composition of the Ni-based alloy for the casting part of the steam turbine according to the present invention is melted by means of vacuum induction melting (VIM) or electric furnace (EF), and decarburized by means of argon-oxygen decarburization (AOD). The thus obtained hot melt is injected into a cylindrical molding box under the condition that the cylindrical molding box is rotated at high rotation speed. In this case, since the hot melt is pressurized by the centrifugal force originated from the rotation of the cylindrical molding box, the thus obtained ingot is formed in a predetermined pipe shape, and then, treated by means of solution treatment. In this way, the pipe for the steam turbine can be manufactured (centrifugal casting method).

[0051] The manufacturing methods for the turbine casing, the valve casing, the nozzle box and the pipe are not limited to the above-described ones.

[0052] The excellent high temperature strength, castability and weldability of the Ni-based alloy for the casting part of the steam turbine will be described hereinafter.

(Evaluation of High Temperature Strength, Castability and Weldability)

[0053] Here, the excellent high temperature strength, castability and weldability of the Ni-based alloy for the casting part of the steam turbine, which has a composition within the composition range defined according to the present invention as described above, will be described. Table 1 shows the chemical compositions of Sample 1 to Sample 28 which are supplied for the evaluation of high temperature strength, the castability and the weldability. The chemical compositions of Sample 1 to Sample 6 are belonging to the chemical composition range defined in the present invention. The chemical compositions of Sample 7 to Sample 28 are not belonging to the chemical composition range defined in the present invention. Therefore, Sample 7 to Sample 28 correspond to Comparative Examples, respectively. Sample 7 has a

EP 2 206 795 A2

chemical composition equal to the chemical composition of a conventional Inconel Alloy 617. In this case, the Ni-based alloy of each of Samples contains iron (Fe), copper (Cu) and sulfur (S) in addition to silicon (Si) and manganese (Mn) as unavoidable impurities.

[0054]

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[Table 1]

(% by mass)																
		Ni	C	Si	Mn	Cr	Fe	Al	Mo	Co	Cu	Ti	B	S	Ta	Nb
Example	Sample 1	Balance	0.051	less than 0.01	less than 0.01	23.2	1.55	1.72	9.05	12.49	0.25	0.35	0.0038	0.0012	0.11	0
	Sample 2	Balance	0.049	less than 0.01	less than 0.01	23.38	1.58	1.77	9.19	12.73	0.24	0.33	0.0031	0.0006	0.69	0
	Sample 3	Balance	0.052	less than 0.01	less than 0.01	22.58	1.48	1.75	9.20	12.28	0.24	0.32	0.0019	0.0010	0	0.10
	Sample 4	Balance	0.051	less than 0.01	less than 0.01	23.27	1.57	1.77	9.21	12.73	0.24	0.34	0.0032	0.0008	0	0.37
	Sample 5	Balance	0.050	less than 0.01	less than 0.01	23.40	1.59	1.78	9.23	12.72	0.24	0.33	0.0032	0.0005	Ta+2Nb=0.15 (Ta: 0.05,2Nb:0.1)	
	Sample 6	Balance	0.050	less than 0.01	less than 0.01	23.50	1.58	1.78	9.22	12.50	0.24	0.35	0.0030	0.0010	Ta+2Nb=0.6 (Ta: 0.2,2Nb:0.4)	
	Sample 7	Balance	0.098	0.51	0.55	23.14	1.51	1.27	9.12	12.32	0.25	0.35	0.0040	0.0009	0	0
	Sample 8	Balance	0.095	less than 0.01	less than 0.01	22.43	1.46	1.28	9.09	12.29	0.23	0.30	0.0030	0.0008	0	0
	Sample 9	Balance	0.010	less than 0.01	less than 0.01	22.44	1.53	1.24	9.15	12.23	0.23	0.33	0.0020	0.0011	0	0
	Sample 10	Balance	0.172	less than 0.01	less than 0.01	22.80	1.53	1.32	9.11	12.52	0.25	0.28	0.0032	0.0008	0	0

(continued)

(% by mass)																
		Ni	C	Si	Mn	Cr	Fe	Al	Mo	Co	Cu	Ti	B	S	Ta	Nb
	Sample 11	Balance	0.096	less than 0.01	less than 0.01	17.85	1.44	1.24	9.20	12.17	0.23	0.30	0.0020	0.0013	0	0
	Sample 12	Balance	0.097	less than 0.01	less than 0.01	28.32	1.55	1.23	9.15	12.33	0.24	0.35	0.0038	0.0010	0	0
	Sample 13	Balance	0.095	less than 0.01	less than 0.01	22.90	1.48	1.20	7.86	12.30	0.25	0.35	0.0035	0.0010	0	0
	Sample 14	Balance	0.099	less than 0.01	less than 0.01	23.11	1.55	1.22	13.05	12.22	0.25	0.33	0.0038	0.0012	0	0
	Sample 15	Balance	0.094	less than 0.01	less than 0.01	22.67	1.47	1.25	9.19	8.90	0.24	0.30	0.0024	0.0005	0	0
	Sample 16	Balance	0.096	less than 0.01	less than 0.01	22.29	1.44	1.24	8.88	16.82	0.23	0.31	0.0031	0.0013	0	0
	Sample 17	Balance	0.097	less than 0.01	less than 0.01	22.78	1.55	1.41	9.12	12.45	0.25	0.35	0.0040	0.0010	0	0
Comparative Example	Sample 18	Balance	0.099	less than 0.01	less than 0.01	23.11	1.48	2.24	9.18	12.38	0.25	0.33	0.0036	0.0010	0	0
	Sample 19	Balance	0.096	less than 0.01	less than 0.01	23.20	1.42	1.25	9.11	12.33	0.25	0.08	0.0038	0.0010	0	0
	Sample 20	Balance	0.095	less than 0.01	less than 0.01	22.42	1.49	1.27	9.08	12.39	0.23	3.25	0.0033	0.0009	0	0

(continued)

(% by mass)																
		Ni	C	Si	Mn	Cr	Fe	Al	Mo	Co	Cu	Ti	B	S	Ta	Nb
	Sample 21	Balance	0.097	less than 0.01	less than 0.01	22.85	1.51	1.33	9.00	12.35	0.25	0.31	0.0006	0.0011	0	0
	Sample 22	Balance	0.095	less than 0.01	less than 0.01	22.68	1.55	1.28	9.13	12.28	0.25	0.35	0.0072	0.0010	0	0
	Sample 23	Balance	0.099	less than 0.01	less than 0.01	23.20	1.55	1.31	9.05	12.49	0.25	0.35	0.0038	0.0012	0.08	0
	Sample 24	Balance	0.087	less than 0.01	less than 0.01	22.65	1.61	1.33	9.14	12.39	0.24	0.30	0.0041	0.0010	1.20	0
	Sample 25	Balance	0.091	less than 0.01	less than 0.01	22.58	1.46	1.26	9.20	12.28	0.24	0.32	0.0019	0.0010	0	0.06
	Sample 26	Balance	0.088	less than 0.01	less than 0.01	22.69	1.53	1.21	9.15	12.30	0.24	0.35	0.0032	0.0010	0	0.64
	Sample 27	Balance	0.090	less than 0.01	less than 0.01	22.75	1.44	1.29	9.01	12.40	0.25	0.32	0.0031	0.0008	Ta+2Nb=0.08 (Ta: 0.02,2Nb:0.06)	
	Sample 28	Balance	0.092	less than 0.01	less than 0.01	23.10	1.47	1.33	9.00	12.39	0.25	0.32	0.0029	0.0008	Ta+2Nb=1.0 (Ta: 0.3,2Nb:0.7)	

[0055] The high temperature strength was evaluated by tensile strength test. In the tensile strength test, 20 kg of the Ni-based alloy was melted in vacuum induction melting furnace to form an ingot per Sample (i.e., Sample 1 to Sample 28). As described above, Sample 1 to Sample 28 have the corresponding chemical composition listed in Table 1. Subsequently, solution treatment was conducted for the ingot for four hours at 1180°C to form a cast steel. Then, each of Samples was prepared in a predetermined size from the cast steel.

[0056] Then, the tensile strength test was conducted per Sample on JIS G 0567 (Method of elevated temperature tensile test for steels and heat-resisting alloys) at temperatures of 23°C, 700°C and 800°C. In this case, 0.2% proof stress was measured. The testing temperatures of 700°C and 800°C were set in view of the temperature condition and the safety factor thereof at a normal operation of a steam turbine. The measurement result of the 0.2% proof stress is listed per Sample in Table 2.

[0057] Moreover, castability was evaluated per Sample. In the evaluation, the ingot relating to Sample was divided vertically into two ingot pieces. Then, liquid penetrant test (PT) of welded heat affected zone was conducted for the divided surface of the ingot piece on JIS Z 2343-1 (Non-destructive testing -- Penetrant testing -- Part 1: General principles -- Method for liquid penetrant testing and classification of the penetrant indication). Then, the occurrence of casting crack was visually evaluated. The castability evaluation result is listed per Sample in Table 2. Here, the case of no casting crack is indicated by the term "not occurrence". In this case, since the castability is excellent, the castability evaluation is indicated by the symbol "○". The case of casting crack is indicated by the term "occurrence". In this case, since the castability is poor, the castability evaluation is indicated by the symbol "×".

[0058] Moreover, weldability was evaluated per Sample. In this case, the sample size was set to 60 mm in width, 150 mm in length and 40 mm in thickness when each of Samples was formed from the corresponding ingot. A trench with a width of 10 mm and a depth of 5 mm was formed at each of Samples so as to be elongated along the long direction thereof at almost the center in the width direction thereof. Then, arc heating to be employed in TIG welding was conducted for the trench so that each of Samples was cut off in the thickness direction at the trench so as to be parallel to the width direction. Then, liquid penetrant test (PT) of welded heat affected zone was conducted for the cutting surface of each of Samples on JIS Z 2343-1 (Non-destructive testing Penetrant testing -- Part 1: General principles -- Method for liquid penetrant testing and classification of the penetrant indication). Then, the occurrence of weld crack was visually evaluated for each of Samples. The welding evaluation result is listed per Sample in Table 2. Here, the case of no weld crack is indicated by the term "not occurrence". In this case, since the weldability is excellent, the welding evaluation is indicated by the symbol "○". The case of weld crack is indicated by the term "occurrence". In this case, since the weldability is poor, the welding evaluation is indicated by the symbol "×".

[0059]

[Table 2]

		0.2% proof stress, Mpa			Castability		Weldability	
		23°C	700°C	800°C	Casting crack	Evaluation	Welding crack	Evaluation
Example	Sample 1	364	306	298	Not occurrence	○	Not occurrence	○
	Sample 2	366	324	311	Not occurrence	○	Not occurrence	○
	Sample 3	360	304	281	Not occurrence	○	Not occurrence	○
	Sample 4	361	309	297	Not occurrence	○	Not occurrence	○
	Sample 5	365	318	301	Not occurrence	○	Not occurrence	○
	Sample 6	370	332	313	Not occurrence	○	Not occurrence	○
	Sample 7	279	216	204	Not occurrence	○	Not occurrence	○
	Sample 8	281	225	214	Not occurrence	○	Not occurrence	○

EP 2 206 795 A2

(continued)

		0.2% proof stress,Mpa			Castability		Weldability	
		23°C	700°C	800°C	Casting crack	Evaluation	Welding crack	Evaluation
Comparative Example	Sample 9	233	121	111	Not occurrence	○	Not occurrence	○
	Sample 10	300	271	252	Occurrence	×	Occurrence	×
	Sample 11	284	217	203	Not occurrence	○	Not occurrence	○
	Sample 12	287	222	207	Not occurrence	○	Not occurrence	○
	Sample 13	281	220	211	Not occurrence	○	Not occurrence	○
	Sample 14	289	239	222	Occurrence	×	Not occurrence	○
	Sample 15	285	213	197	Not occurrence	○	Not occurrence	○
	Sample 16	303	238	224	Occurrence	×	Occurrence	×
	Sample 17	324	245	223	Not occurrence	○	Not occurrence	○
	Sample 18	474	409	302	Occurrence	×	Occurrence	×
	Sample 19	268	203	194	Not occurrence	○	Not occurrence	○
	Sample 20	395	285	253	Occurrence	×	Occurrence	×
	Sample 21	281	213	201	Not occurrence	○	Not occurrence	○
	Sample 22	292	218	207	Not occurrence	○	Not occurrence	○
	Sample 23	286	220	211	Not occurrence	○	Not occurrence	○
	Sample 24	297	246	230	Occurrence	×	Not occurrence	○
	Sample 25	283	228	211	Not occurrence	○	Not occurrence	○
	Sample 26	292	235	226	Not occurrence	○	Not occurrence	○
	Sample 27	283	223	210	Not occurrence	○	Not occurrence	○
	Sample 28	293	238	229	Not occurrence	○	Not occurrence	○

[0060] It was turned out that Sample 1 to Sample 6 have respective higher 0.2% proof stresses, and excellent castability and weldability. The reason why Sample 1 to Sample 6 have the respective higher 0.2% proof stresses is considered due to precipitation strengthening and solute strengthening.

[0061] For example, in contrast, Sample 18 and Sample 20 have the respective higher 0.2% proof stresses, but poor castability and weldability. All of the conventional steels relating to Comparative Examples cannot exhibit excellent high temperature strength, castability and weldability.

[0062] Although the present invention was described in detail with reference to the above examples, this invention is not limited to the above disclosure and every kind of variation and modification may be made without departing from the scope of the present invention.

Claims

1. A Ni-based alloy for a casting part of a steam turbine having excellent high temperature strength, castability and weldability, comprising,
in percentage by mass, 0.01 to 0.15 of C, 18 to 28 of Cr, 10 to 15 of Co, 8 to 12 of Mo, 1.5 to 2 of Al, 0.1 to 3 of Ti, 0.001 to 0.006 of B, 0.1 to 0.7 of Ta, and the balance of Ni plus unavoidable impurities.
2. The Ni-based alloy as set forth in claim 1,
wherein contents of at least Si and Mn selected from among the unavoidable impurities are set to 0.1 or less, respectively.
3. A Ni-based alloy for a casting part of a steam turbine having excellent high temperature strength, castability and weldability, comprising,
in percentage by mass, 0.01 to 0.15 of C, 18 to 28 of Cr, 10 to 15 of Co, 8 to 12 of Mo, 1.5 to 2 of Al, 0.1 to 3 of Ti, 0.001 to 0.006 of B, 0.1 to 0.4 of Nb, and the balance of Ni plus unavoidable impurities.
4. The Ni-based alloy as set forth in claim 3,
wherein contents of at least Si and Mn selected from among the unavoidable impurities are set to 0.1 or less, respectively.
5. A Ni-based alloy for a casting part of a steam turbine having excellent high temperature strength, castability and weldability, comprising,
in percentage by mass, 0.01 to 0.15 of C, 18 to 28 of Cr, 10 to 15 of Co, 8 to 12 of Mo, 1.5 to 2 of Al, 0.1 to 3 of Ti, 0.001 to 0.006 of B, 0.1 to 0.7 of Ta + 2Nb (Ta:Nb in mole ratio is 1:2), and the balance of Ni plus unavoidable impurities.
6. The Ni-based alloy as set forth in claim 5,
wherein contents of at least Si and Mn selected from among the unavoidable impurities are set to 0.1 or less, respectively.
7. A turbine casing of a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 1 through casting.
8. A turbine casing of a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 3 through casting.
9. A turbine casing of a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 5 through casting.
10. A valve casing of a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 1 through casting.
11. A valve casing of a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 3 through casting.
12. A valve casing of a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 5 through casting.
13. A nozzle box of a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 1 through casting.
14. A nozzle box of a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 3 through casting.

15. A nozzle box of a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 5 through casting.

5 16. A pipe for a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 1 through casting.

17. A pipe for a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 3 through casting.

10 18. A pipe for a steam turbine, comprising,
at least a portion made of a Ni-based alloy as set forth in claim 5 through casting.

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REFERENCES CITED IN THE DESCRIPTION

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