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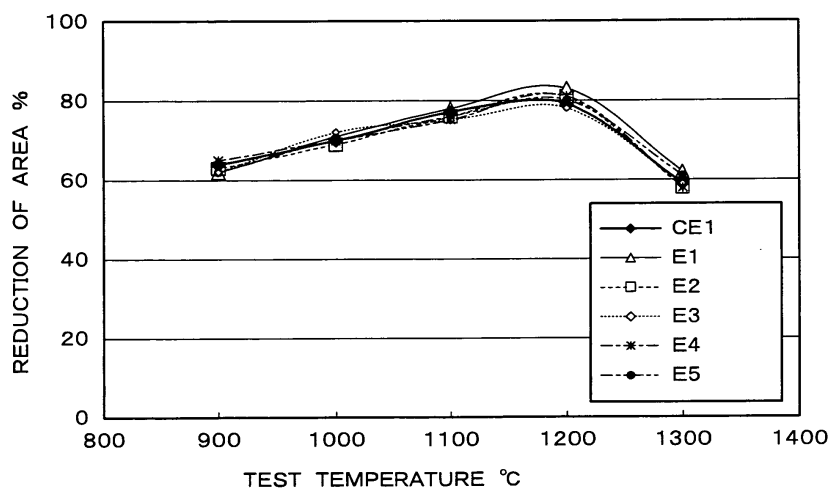
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(54) **Nickel-base alloy for a steam turbine rotor and steam turbine rotor thereof**

(57) A nickel (Ni)-base alloy for a turbine rotor of a steam turbine containing, in mass%, carbon (C): 0.01% to 0.15%, chromium (Cr): 18% to 28%, cobalt (Co): 10%

to 15%, molybdenum (Mo): 8% to 12%, aluminum (Al): 0.5% to less than 1.5%, titanium (Ti): 0.7% to 3.0%, and boron (B): 0.001% to 0.006%, the balance being nickel (Ni) and unavoidable impurities.

FIG. 2



Description**BACKGROUND OF THE INVENTION****1. FIELD OF THE INVENTION**

[0001] The present invention relates to a nickel-base alloy for a turbine rotor of a steam turbine, and a turbine rotor of a steam turbine using this nickel-base alloy.

2. DESCRIPTION OF THE RELATED ART

[0002] In a thermal power plant, technology to cut emissions of carbon dioxide is gaining attention in view of preserving global environment, and there are increasing needs for increase in efficiency of power generation. To increase the power generating efficiency of a steam turbine, it is effective to raise steam temperature in the steam turbine. In thermal power plants of late years, the steam temperature in the turbine is increased to 600°C or higher, and it is expected to be increased to 650°C, and further to 700°C or higher in the future.

[0003] Around a turbine rotor supporting rotor blades which rotate by receiving high-temperature steam, the high-temperature steam circulates and increases its temperature, and high stress occurs by the rotation. Accordingly, the turbine rotor of the steam turbine is required to endure high temperature and high stress, and as a material forming the turbine rotor, there is demanded an alloy having high strength, ductility, and toughness in a region ranging from room temperature to high temperature.

[0004] Particularly when the steam temperature is over 700°C, conventional iron-base materials have insufficient high temperature strength, and therefore use of nickel (Ni)-base alloys is considered (see, for example, JP-A 7-150277 (KOKAI)). Due to its excellent high temperature strength and corrosion resistance, the Ni-base alloys have been widely used mainly as materials for jet engines and gas turbines. Typical examples include Inconel 617 alloy (manufactured by Special Metals Corporation) and Inconel 706 alloy (manufactured by Special Metals Corporation).

[0005] As a mechanism to enhance the high temperature strength of a Ni-base alloy, there is known one in which a precipitation phase called a gamma prime phase ($\text{Ni}_3(\text{Al}, \text{Ti})$) or a gamma double prime phase (Ni_3Nb) is precipitated or both the phases are precipitated in the matrix of the Ni-base alloy by adding Al and Ti, to thereby ensure the high temperature strength. The Inconel 706 alloy is one such example.

[0006] Further, there are also known Ni-base alloys in which Co, Mo are added to strengthen (solid solution strengthening) a matrix of the Ni base to ensure high temperature strength, such as Inconel 617 alloy.

[0007] As described above, as a turbine rotor material for a steam turbine whose temperature exceeds 700°C, there is considered use of Ni-base alloys having higher high temperature strength than that of iron-base materials, and there is demanded improvement in composition to satisfy high temperature strength, forgeability, and the like, while maintaining hot workability of the Ni-base alloys.

[0008] An object of the present invention is to provide a Ni-base alloy for a turbine rotor of a steam turbine that is excellent in both high temperature strength and forgeability while maintaining the hot workability, and provide a turbine rotor of a steam turbine using the same.

SUMMARY OF THE INVENTION

[0009] An aspect of a nickel-base alloy for a turbine rotor of a steam turbine according to the present invention contains, in mass%, C: 0.01% to 0.15%, Cr: 18% to 28%, Co: 10% to 15%, Mo: 8% to 12%, Al: 0.5% to less than 1.5%, Ti: 0.7% to 3.0%, and B: 0.001% to 0.006%, the balance being nickel (Ni) and unavoidable impurities.

[0010] An aspect of a turbine rotor of a steam turbine according to the present invention is a turbine rotor provided to penetrate through a steam turbine to which high-temperature steam is introduced, in which at least a predetermined portion is constituted of the above-described nickel-base alloy for a turbine rotor of a steam turbine.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a constitution picture of a Ni-base alloy according to an embodiment of the present invention.

[0012] FIG. 2 is a graph showing results of a Greeble test.

[0013] FIG. 3 is a constitution picture of a Ni-base alloy.

[0014] FIG. 4 is a constitution picture of an Inconel 617 alloy.

DETAILED DESCRIPTION OF THE INVENTION

[0015] Hereinafter, an embodiment of a nickel (Ni)-base alloy for a turbine rotor of a steam turbine according to the present invention and a turbine rotor of a steam turbine formed from this alloy will be described.

[0016] Ni-base alloys such as Inconel 706 alloy and Inconel 617 alloy are quite useful as turbine rotor materials. However, for further increase in efficiency of steam turbine power generating equipment, the Ni-base alloys are required to have satisfactory high temperature strength (mechanical strength at high temperature) and forgeability while maintaining hot workability (drawing or the like).

[0017] For example, Inconel 617 alloy is an alloy with high temperature strength improved by solid solution strengthening of matrix of a Ni base by adding cobalt (Co) and molybdenum (Mo). However, for further improving the high temperature strength, the solid solution strengthening alone is not always sufficient. Accordingly, the Ni-base alloy for a turbine rotor of this embodiment is further strengthened using precipitation strengthening besides the solid solution strengthening.

[0018] Details of this further strengthening will be described below. The Ni-base alloy for a turbine rotor of a steam turbine of this embodiment is based on the composition of Inconel 617 as a representative Ni-base alloy, and is improved in strength characteristics at high temperature and forgeability by performing addition and adjustment.

[0019] Ti content in the conventional Inconel 617 alloy is approximately 0.6% by mass, and the precipitation strengthening cannot be expected with this degree of content. Accordingly, the Ti content is increased to 0.7% to 3.0% by mass, so as to increase the amount of γ' phase (gamma prime phase ($\text{Ni}_3(\text{Al}, \text{Ti})$)) to be precipitated. A constitution picture of a Ni-base alloy is shown in FIG. 3, in which Al concentration is increased to 1.6% by mass or higher and Ti concentration is increased to 0.7% by mass or higher so as to further improve the high temperature strength. In FIG. 3, precipitation of a damaging phase called a σ phase is recognized as shown by an arrow. In addition, the composition of the Ni-base alloy shown in FIG. 3 is Ni-1.8Al-1.3Ti-23Cr-12Co-9Mo-0.1Ta-0.3Nb (the number attached to the head of each constituent denotes the content (% by mass) of this constituent, and the balance being Ni). Thus, in the present invention, to prevent the precipitation of the embrittlement phase, the Al concentration is adjusted in the range of 0.5% to less than 1.5% by mass and tantalum (Ta) and niobium (Nb) are added as necessary, so as to allow stable precipitation of the γ' phase and improve stability of the γ' phase itself. Consequently, further strengthening of this Ni-base alloy is achieved.

[0020] The Ni-base alloy for a turbine rotor of a steam turbine of this embodiment can be implemented as follows.

(Alloy 1) A Ni-base alloy for a turbine rotor of a steam turbine, the alloy containing, in mass%, C: 0.01% to 0.15%, Cr: 18% to 28%, Co: 10% to 15%, Mo: 8% to 12%, Al: 0.5% to less than 1.5%, Ti: 0.7% to 3.0%, and B: 0.001% to 0.006%, the balance being Ni and unavoidable impurities.

(Alloy 2) A Ni-base alloy for a turbine rotor of a steam turbine, the alloy containing, in mass%, C: 0.01% to 0.15%, Cr: 18% to 28%, Co: 10% to 15%, Mo: 8% to 12%, Al: 0.5% to less than 1.5%, Ti: 0.7% to 3.0%, B: 0.001% to 0.006%, and Ta: 0.1% to 0.7%, the balance being Ni and unavoidable impurities.

(Alloy 3) A Ni-base alloy for a turbine rotor of a steam turbine, the alloy containing, in mass%, C: 0.01% to 0.15%, Cr: 18% to 28%, Co: 10% to 15%, Mo: 8% to 12%, Al: 0.5% to less than 1.5%, Ti: 0.7% to 3.0%, B: 0.001% to 0.006%, and Nb: 0.1% to 0.4%, the balance being Ni and unavoidable impurities.

(Alloy 4) A Ni-base alloy for a turbine rotor of a steam turbine, the alloy containing, in mass%, C: 0.01% to 0.15%, Cr: 18% to 28%, Co: 10% to 15%, Mo: 8% to 12%, Al: 0.5% to less than 1.5%, Ti: 0.7% to 3.0%, B: 0.001% to 0.006%, Ta: 0.1% to 0.7%, and Nb: 0.1% to 0.4%, the balance being Ni and unavoidable impurities.

(Alloy 5) A Ni-base alloy for a turbine rotor of a steam turbine, the alloy containing, in mass%, C: 0.01% to 0.15%, Cr: 18% to 28%, Co: 10% to 15%, Mo: 8% to 12%, Al: 0.5% to less than 1.5%, Ti: 0.7% to 3.0%, B: 0.001% to 0.006%, and Ta+2Nb (mole ratio of Ta and Nb being 1:2): 0.1% to 0.7%, the balance being Ni and unavoidable impurities.

Note that in the following description, "%" representing a constituent of an alloy means "% by mass" unless otherwise specified.

[0021] Here, in the Ni-base alloys for a turbine rotor of a steam turbine, namely, the above-described (alloy 1) to (alloy 5), it is preferred that among the unavoidable impurities at least the Si content is reduced to 0.1% or less and the Mn content to 0.1% or less. Next, reasons for the limitations of constituent ranges in the respective compositions of the above-described Ni-base alloys for a turbine rotor of a steam turbine of this embodiment will be described.

(1) C (carbon)

[0022] C is useful as a constitutional element of M_{23}C_6 type carbide as a strengthened phase, and one of factors of maintaining creep strength of an alloy is to cause the M_{23}C_6 type carbide to precipitate while the turbine is operating, particularly under a high-temperature environment at 650°C or higher. Further, it also has an effect to secure fluidity of

molten metal during casting. When the content of C is less than 0.01% a sufficient precipitation amount of the carbide cannot be secured. Thus, the high temperature strength decreases, and the fluidity of molten metal during casting decreases significantly. On the other hand, when the content of C is over 0.15%, a constituent segregation trend increases when producing a large ingot, generation of M_6C type carbide as an embrittlement phase is facilitated, and further the high temperature strength improves, but forgeability decreases. Thus, the content of C is limited in the range of 0.01% to 0.15%.

(2) Cr (chromium)

[0023] Cr is an essential element to enhance oxidation resistance, corrosion resistance and high temperature strength of the Ni-base alloys. Moreover, it is essential as a constitutional element of the $M_{23}C_6$ type carbide, and creep strength of the alloy is maintained by allowing the $M_{23}C_6$ type carbide to precipitate while the turbine is operating, particularly under a high-temperature environment at 650°C or higher. Further, Cr can increase oxidation resistance under a high-temperature steam environment. When the content of Cr is less than 18%, the oxidation resistance decreases. On the other hand, when the content of Cr is over 28%, a trend to be coarse is enhanced by significantly facilitating the precipitation of the $M_{23}C_6$ type carbide. Thus, the content of Cr is limited in the range of 18% to 28%.

(3) Co (cobalt)

[0024] Co has an effect to strengthen a parent phase in the Ni-base alloys by solid-solving into the parent phase. When the content of Co is less than 10%, the high temperature strength decreases. On the other hand, when the content of Co is over 15%, a weakening intermetallic compound phase is generated, and moreover forgeability decreases. Thus, the content of Co is limited in the range of 10% to 15%.

(4) Mo (molybdenum)

[0025] Mo has an effect to enhance the strength of the matrix by solute effect. Further, Mo partially replaces the $M_{23}C_6$ type carbide, and thereby stability of the carbide can be improved. When the content of Mo is less than 8%, the above-described effect is not exhibited, and when the content of Mo is over 12%, the component segregation trend when producing a large ingot increases and generation of M_6C type carbide as an embrittlement phase is facilitated. Thus, the content of Mo is limited in the range of 8% to 12%.

(5) Al (aluminum)

[0026] Al generates a γ' phase together with Ni and thereby can improve strength of the Ni-base alloys by precipitation. When the content of Al is less than 0.5%, the high temperature strength decreases. On the other hand, when the content of Al is 1.5% or more, it may facilitate precipitation of an embrittlement phase which is referred to as a σ phase, along with decrease in forgeability. Thus, the content of Al is limited in the range of 0.5% to less than 1.5%.

(6) Ti (titanium)

[0027] Ti generates the γ' phase together with Ni similarly to Al, and hence can strengthen the Ni-base alloys. When the content of Ti is less than 0.7%, the high temperature strength is equal to that of the conventional material. On the other hand, when the content of Ti is over 3%, hot workability decreases, possibly resulting in decrease of forgeability and increase of notch sensitivity. Thus, the content of Ti is limited in the range of 0.7% to 3.0%.

(7) B (boron)

[0028] B is segregated in a grain boundary to improve high-temperature properties. This effect can be exhibited when the content of B is 0.001% or more. However, when the content of B is over 0.006%, it may lead to grain boundary embrittlement. Thus, the content of B is limited in the range of 0.001% to 0.006%.

(8) Ta (tantalum)

[0029] Ta has an effect to stabilize a precipitation strengthened phase by solid-solving in the γ' phase. When the content of Ta is less than 0.1%, the stabilization effect is not exhibited. On the other hand, when the content of Ta is over 0.7%, the high temperature strength improves but forgeability decreases. Thus, the content of Ta is limited in the range of 0.1% to 0.7%.

(9) Nb (niobium)

[0030] Nb has an effect to enhance the high temperature strength and stabilize the γ' phase by solid-soluble similarly to Ta. When the content of Nb is less than 0.1%, the above-described effect is not occurred, and when the content of Nb is over 0.4%, the high temperature strength improves but forgeability decreases. Thus, the content of Nb is limited in the range of 0.1% to 0.4%. Further, by containing the above-described Ta and Nb such that the content of (Ta+2Nb) is in the range of 0.1% to 0.7%, they are solid-soluble in the γ' phase to enhance the high temperature strength and stabilize the γ' phase precipitation. When the content of (Ta+2Nb) is less than 0.1%, no improvement is seen in the above-described effect as compared to the conventional material. On the other hand, when the content of (Ta+2Nb) is over 0.7%, the high temperature strength improves but the forgeability decreases. Incidentally, in this case, Ta and Nb are each contained by at least 0.01% or more.

(10) Si (silicon), Mn (manganese), Fe (iron), Cu (copper), and S (sulfur)

[0031] Si, Mn, Fe, Cu, and S are classified as unavoidable impurities in the Ni-base alloys for a turbine rotor of a steam turbine of this embodiment. It is desired that the remaining contents of these unavoidable impurities are made close to 0(zero)% as much as possible. Further, among these unavoidable impurities, it is preferred that at least Si and Mn are each suppressed to 0.1% or less. In the case of ordinary steel, Mn prevents brittleness by turning S (sulfur) contributing to brittleness to MnS. However, the content of S in the Ni-base alloys is quite small, and it is not necessary to add Mn. Accordingly, in the Ni-base alloys for a turbine rotor of a steam turbine of this embodiment, it is desired that the content of Mn is 0.1% or less and the remaining content thereof is close to 0(zero)% as much as possible. Si is added to complement corrosion resistance in the case of ordinary steel. However, in the Ni-base alloys, the content of Cr is large and the corrosion resistance can be ensured sufficiently. Thus, in the Ni-base alloys for a turbine rotor of a steam turbine of this embodiment, it is desired that the content of Si is 0.1% or less and the remaining content thereof is close to 0 (zero)% as much as possible.

[0032] FIG. 4 shows microstructure of a conventional Inconel 617 alloy. FIG. 1 [composition: Ni-0.05C-1.15Al-1.8Ti-23Cr-12Co-9Mo-0.1Ta-0.3Nb-0.003B] shows microstructure of one of the Ni-base alloys for a turbine rotor of a steam turbine of this embodiment. As shown in FIG. 1, in the Ni-base alloy for a turbine rotor of a steam turbine of this embodiment, it is possible to allow stable precipitation of fine γ' in the γ matrix as shown by an arrow while suppressing the precipitation of the σ phase, by the above-described alloy composition ranges.

[0033] Next, a preferred manufacturing method for the Ni-base alloys for a turbine rotor of a steam turbine of this embodiment will be described. An alloy whose constituents are adjusted as described above is melted and casted in the usual manner. Thereafter, this ingot is subjected to a stabilization treatment, ordinary hot forging, and a solution treatment. In the solution treatment after the forging, it is desired that the temperature is not lower than the melting temperature of the γ' phase and not higher than the local melting starting temperature thereof. Although conditions of the stabilization treatment and the solution treatment vary depending on the alloy composition and the size of a treated object, the stabilization processing can be performed by heating for 3 to 72 hours in a temperature range of 1000°C to 1250°C, for example. On the other hand, the solution treatment can be performed by heating for 3 to 24 hours in a temperature range of 1000°C to 1200°C and by quenching thereafter, for example. These treatments may be one that is performed in multiple stages. Moreover, as necessary, early precipitation of the γ' phase can be achieved by performing an aging treatment for 3 to 24 hours in a temperature range of 700°C to 800°C.

(Evaluation of high temperature properties and manufacturability)

[0034] The embodiment will be described with reference to tables, regarding alloy compositions, high temperature properties, and manufacturability of the Ni-base alloys. By melting in a vacuum induction furnace followed by forging, 26 types materials, their chemical composition are shown in Table 1, were obtained. For evaluating ranges of added amounts of respective elements shown in this embodiment, added amounts of 21 types of comparative examples are adjusted to be out of the ranges. Remaining five types are examples. Incidentally, comparative example 1 has chemical constituents equivalent to Inconel 617 alloy as a conventional material. Si, Mn, Fe, Cu, S in Table 1 are mixed in unavoidably.

[0035]

[Table 1]

Mass (%)														
	Ni	C	Si	Mn	Cr	Fe	Al	Mo	Co	Cu	Ti	B	S	Nb
CE1	Bal.	0.098	0.51	0.55	23.14	1.51	1.27	9.12	12.32	0.25	0.35	0.004	0.0009	0
CE2	Bal.	0.008	<0.01	<0.01	22.44	1.53	1.24	9.15	12.23	0.23	1.36	0.0020	0.0011	0
CE3	Bal.	0.172	<0.01	<0.01	22.80	1.53	1.32	9.11	12.52	0.25	1.32	0.0032	0.0008	0
CE4	Bal.	0.096	<0.01	<0.01	17.85	1.44	1.24	9.20	12.17	0.23	1.33	0.0020	0.0013	0
CE5	Bal.	0.097	<0.01	<0.01	28.32	1.55	1.23	9.15	12.33	0.24	1.34	0.0038	0.0010	0
CE6	Bal.	0.094	<0.01	<0.01	22.67	1.47	1.25	9.19	8.9	0.24	1.33	0.0024	0.0005	0
CE7	Bal.	0.096	<0.01	<0.01	22.29	1.44	1.24	8.88	16.82	0.23	1.31	0.0031	0.0013	0
CE8	Bal.	0.095	<0.01	<0.01	22.9	1.48	1.2	7.86	12.3	0.25	1.32	0.0035	0.0010	0
CE9	Bal.	0.099	<0.01	<0.01	23.11	1.55	1.22	13.05	12.22	0.25	1.31	0.0038	0.0012	0
CE10	Bal.	0.096	<0.01	<0.01	23.36	1.55	0.45	8.95	12.49	0.23	1.33	0.0031	0.0010	0
CE11	Bal.	0.047	<0.01	<0.01	23.52	1.58	1.71	9.19	12.7	0.24	1.33	0.0029	0.0005	0
CE12	Bal.	0.096	<0.01	<0.01	23.25	1.42	1.16	8.9	12.36	0.25	0.5	0.0031	0.0010	0
CE13	Bal.	0.095	<0.01	<0.01	22.42	1.49	1.27	9.08	12.39	0.23	3.25	0.0033	0.0009	0
CE14	Bal.	0.097	<0.01	<0.01	22.85	1.51	1.33	9.00	12.35	0.25	1.31	0.0006	0.0011	0
CE15	Bal.	0.095	<0.01	<0.01	22.68	1.55	1.28	9.13	12.28	0.25	1.32	0.0072	0.0010	0
CE16	Bal.	0.099	<0.01	<0.01	23.20	1.55	1.31	9.05	12.49	0.25	1.34	0.0038	0.0012	0.08
CE17	Bal.	0.087	<0.01	<0.01	22.65	1.61	1.33	9.14	12.39	0.24	1.35	0.0041	0.0010	1.20
CE18	Bal.	0.091	<0.01	<0.01	22.58	1.46	1.26	9.20	12.28	0.24	1.33	0.0019	0.0010	0
CE19	Bal.	0.088	<0.01	<0.01	22.69	1.53	1.21	9.15	12.30	0.24	1.32	0.0032	0.0010	0
CE20	Bal.	0.090	<0.01	<0.01	22.75	1.44	1.29	9.01	12.40	0.25	1.33	0.0031	0.0008	Ta+2Nb=0.08
CE21	Bal.	0.092	<0.01	<0.01	23.10	1.47	1.33	9.00	12.39	0.25	1.34	0.0029	0.0008	Ta+2Nb=1.0
E1	Bal.	0.046	<0.01	<0.01	23.89	1.47	1.08	9.03	12.51	0.25	1.8	0.0025	0.0008	0
E2	Bal.	0.052	<0.01	<0.01	23.46	1.46	1.19	8.97	12.52	0.25	1.78	0.0028	0.0008	0.12
E3	Bal.	0.047	<0.01	<0.01	23.59	1.46	1.18	8.95	12.59	0.25	1.78	0.0031	0.0009	0

(continued)

Mass (%)															
	Ni	C	Si	Mn	Cr	Fe	Al	Mo	Co	Cu	Ti	B	S	Ta	Nb
E4	Bal.	0.046	<0.01	<0.01	23.69	1.47	1.11	9.03	12.51	0.25	1.69	0.0037	0.0008	0.12	0.32
E5	Bal.	0.046	<0.01	<0.01	23.44	1.44	1.1	8.99	12.6	0.24	1.68	0.0033	0.0009	Ta+2Nb=0.67	
CE = Comparative Example; E = Example															

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[0036] The 26 types of forged materials are each obtained by cutting off the portion of a surface as forged from the surface of a columnar ingot having a diameter of approximately 125 mm and a length of approximately 210 mm. The forged materials after removing the surface scale as forged each had a diameter of 120 mm and a length of 200 mm. These forged materials were subjected to a stabilization treatment for six hours at 1180°C, and immediately thereafter to hot forging. The hot forging was performed until the forging ratio becomes three. In this forging, the temperatures of the forged materials were measured, so as to pause the forging work once for performing reheating at 1180°C when the temperature of the forged materials decrease to 1000°C. When the forging ratio became three, that is, the whole length of each forged article became 600 mm, the forging was finished and the materials were cooled down. The diameter of each forged article at this point was approximately 70 mm. After cooled down, the surface of each forged article was observed to check for the presence of any forging crack.

[0037] Next, each forged article was subjected to a solution treatment in which it is heated for four hours at 1170°C and thereafter quenched. To each forged article after the solution treatment, an aging treatment for ten hours at 750°C was performed. A test piece was sampled appropriately from each forged article after the aging treatment, and was subjected to various types of tests. Results of a tensile strength test (0.2% proof stress) from room temperature (23°C) to high temperature (700°C and 800°C) and forging status are shown in Table 2 for comparative examples 1 to 21 and examples 1 to 5 after the solution treatment and the aging treatment. In addition, the tensile test was performed complying JIS Z 2241 (Method of tensile test for metallic materials). The 700°C and 800°C as temperature conditions in the tensile test are set in view of temperature conditions of a steam turbine in normal operation and temperatures in which safety factors are counted. In Table 2, the "forging ratio" shows values of " L_1/L_0 " where L_0 and L_1 are lengths before and after forging. The "number of reheating" is the number of times of reheating an object being forged until the "forging ratio" becomes three in a forging treatment. The "forging crack" shows results of visual observation for the presence of any "forging crack" after forging, in which "none" indicates one with no "forging crack" and "present" indicates one with a forging crack. The "forgeability" shows results of evaluating forgeability, in which "O" indicates one determined to have good forgeability, and "X" indicates one determined to have poor forgeability.

[0038]

[Table 2]

	0.2% Proof Stress (MPa)			Forging Status (Forging Ratio = 3)		
	23°C	700°C	800°C	Number of Reheating	Forging Crack	Forgeability
CE1	328	254	240	10	none	O
CE2	284	152	140	10	none	O
CE3	363	329	306	15	present	X
CE4	344	265	249	10	none	O
CE5	348	271	253	10	none	O
CE6	345	261	242	10	none	O
CE7	366	290	274	12	present	X
CE8	340	269	258	10	none	O
CE9	350	291	271	12	present	X
CE10	288	140	124	10	none	O
CE11	435	360	336	12	none	X
CE12	365	287	271	10	none	O
CE13	475	345	308	12	present	X
CE14	341	260	247	10	none	O
CE15	353	266	254	10	none	O
CE16	347	269	258	10	none	O
CE17	359	299	281	10	present	X
CE18	343	278	258	10	none	O

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(continued)

	0.2% Proof Stress (MPa)			Forging Status (Forging Ratio = 3)		
	23°C	700°C	800°C	Number of Reheating	Forging Crack	Forgeability
CE19	354	287	276	10	none	O
CE20	343	272	257	10	none	O
CE21	355	290	279	10	none	O
E1	422	377	365	10	none	O
E2	565	496	488	10	none	O
E3	589	523	511	10	none	O
E4	612	559	546	10	none	O
E5	578	535	522	10	none	O
CE = Comparative Example; E = Example						

[0039] As shown in Table 2, the examples 1 to 5 have high 0.2% proof stresses at respective temperatures, and hence are proved to have excellent forgeability. It is found that the examples have both improved high temperature strength and forgeability due to precipitation/solid solution strengthening as compared to the comparative examples.

(Greeble test)

[0040] Table 3 shows results of a Greeble test to evaluate hot workability of the comparative example 1 (equivalent to the conventional material Inconel 617) shown in Table 1 and the examples 1 to 5. The Greeble test was performed at 900°C, 1000°C, 1100°C, 1200°C, and 1300°C at strain rate of 10% distortion/sec. Further, FIG. 2 is a graph showing Greeble test results of each sample shown in Table 3. Here, the horizontal axis of FIG. 2 shows test temperature (°C). Reduction of area (drawing) shown on the vertical axis means a ratio of a cross-sectional area of a test piece after the test (after fractured) decreased from the cross-sectional area of the test piece before the test, to the cross-sectional area of the test piece before the test. In short, when this value is large, it means that the test piece has excellent hot workability.

[0041]

[Table 3]

Test Temperature °C	Drawing (%)					
	CE1	E1	E2	E3	E4	E5
900	64	62	63	62	65	62
1000	70	71	69	72	70	70
1100	77	78	76	75	75	76
1200	79	83	81	78	81	80
1300	59	62	58	59	58	61
CE= Comparative Example; E= Example						

[0042] As shown in Table 3, the examples 1 to 5 are equivalent to the conventional material, and in which a drawing value of 50% or more is secured at 900°C to 1300°C that is a temperature range of forging. Thus it is found that there is no problem in manufacturing.

[0043] The Ni-base alloys for a turbine rotor of a steam turbine of this embodiment make it possible that, by composing in the constituent ranges of the above-described compositions, both the high temperature strength and the forgeability can be improved while maintaining the hot workability of conventional Ni-base alloys. Accordingly, the Ni-base alloys for a turbine rotor of a steam turbine of this embodiment can attain high reliability under a high-temperature environment as a turbine rotor material for a steam turbine to which high-temperature steam is introduced.

[0044] Further, a turbine rotor provided to penetrate through a steam turbine to which high-temperature steam is introduced can be formed from one of the Ni-base alloys for a turbine rotor of a steam turbine of this embodiment. Specifically, the whole of the turbine rotor of a steam turbine may be formed from this Ni-base alloy, or particularly a part of the turbine rotor of the turbine that is subjected to high temperature may be formed from this Ni-base alloy. Here, the part of the turbine rotor of the steam turbine that is subjected to high temperature may be, specifically, the entire area of a high-pressure steam turbine unit, or an area from a high-pressure steam turbine unit to a part of an intermediate-pressure steam turbine unit, and the like. With this turbine rotor, the high temperature strength can be improved, and high reliability is achieved even under a high-temperature environment.

[0045] It should be noted that the present invention is not limited to the above-described embodiment, and as a matter of course, various modifications can be made thereon. Further, the embodiment of the present invention can be extended or modified in the range of the technical idea of the invention, and such extended or modified embodiments are also included in the technical scope of the invention.

Claims

1. A nickel-base alloy for a turbine rotor of a steam turbine, the nickel-base alloy containing, in mass%: carbon (C): 0.01% to 0.15%; chromium (Cr): 18% to 28%; cobalt (Co): 10% to 15%; molybdenum (Mo): 8% to 12%; aluminium (Al): 0.5% to less than 1.5%; titanium (Ti): 0.7% to 3.0%; and boron (B): 0.001% to 0.006%, the balance being nickel (Ni) and unavoidable impurities.
2. The nickel-base alloy for a turbine rotor of a steam turbine according to claim 1, further containing tantalum (Ta): 0.1% to 0.7% by mass.
3. The nickel-base alloy for a turbine rotor of a steam turbine according to claim 1, further containing niobium (Nb): 0.1% to 0.4% by mass.
4. The nickel-base alloy for a turbine rotor of a steam turbine according to claim 2, further containing niobium (Nb): 0.1% to 0.4% by mass.
5. The nickel-base alloy for a turbine rotor of a steam turbine according to claim 1, further containing tantalum + 2niobium (Ta+2Nb) (mole ratio of tantalum and niobium being 1:2): 0.1% to 0.7% by mass.
6. The nickel-base alloy for a turbine rotor of a steam turbine according to claim 1, wherein the unavoidable impurities include silicon (Si): 0.1% or less and manganese (Mn): 0.1% or less by mass.
7. A turbine rotor provided to penetrate through a steam turbine to which high-temperature steam is introduced, wherein at least a predetermined portion is constituted of the nickel-base alloy for a turbine rotor of a steam turbine according to claim 1.
8. The use of an alloy as claimed in any one of claims 1 to 6, in the manufacture of a turbine rotor for a steam turbine.
9. A method of manufacturing a turbine rotor **characterised by** the step of selecting as the material of at least a portion of the rotor a nickel-base alloy as claimed in any one of claims 1 to 6.
10. Method according to claim 9, including a forging step and a step of solution treatment after the forging step, with the temperature of said solution treatment being not lower than the melting temperature of the γ' phase of the alloy.
11. A steam turbine **characterised in that** at least a portion of a turbine rotor of the turbine is of a nickel-base alloy as claimed in any one of claims 1 to 6.
12. A turbine as claimed in claim 10, with an operating temperature in excess of 700°C.

FIG. 1

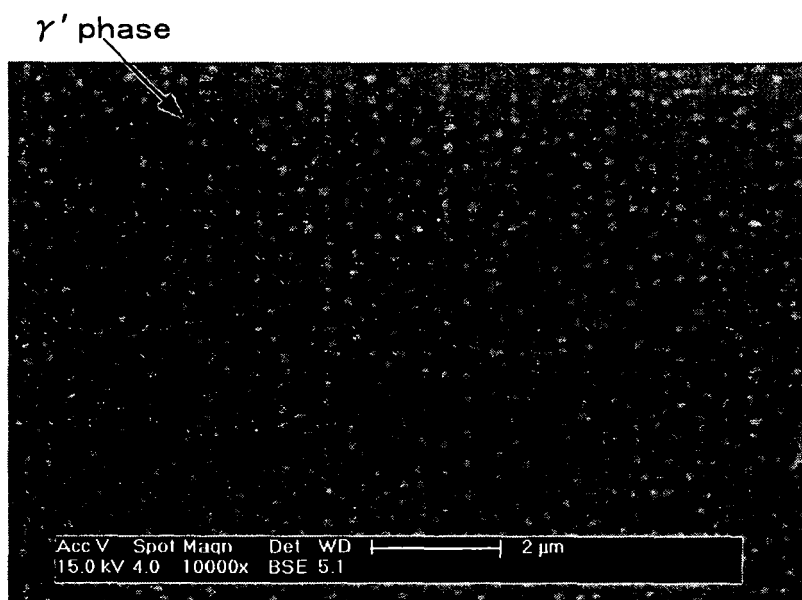


FIG. 2

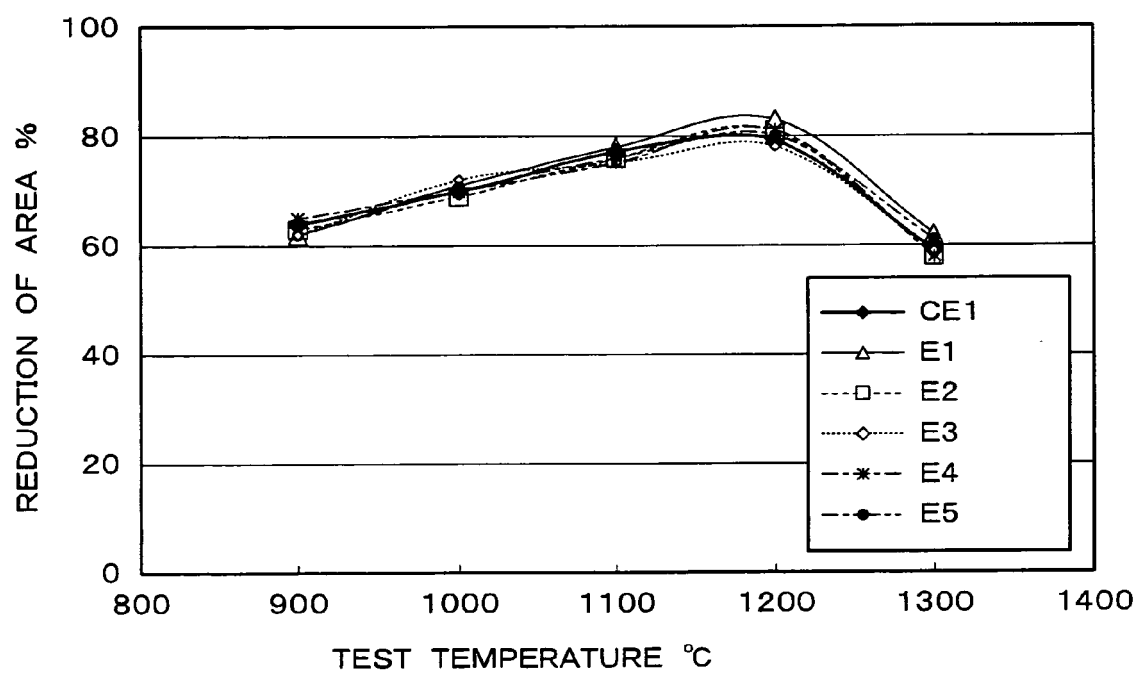


FIG. 3

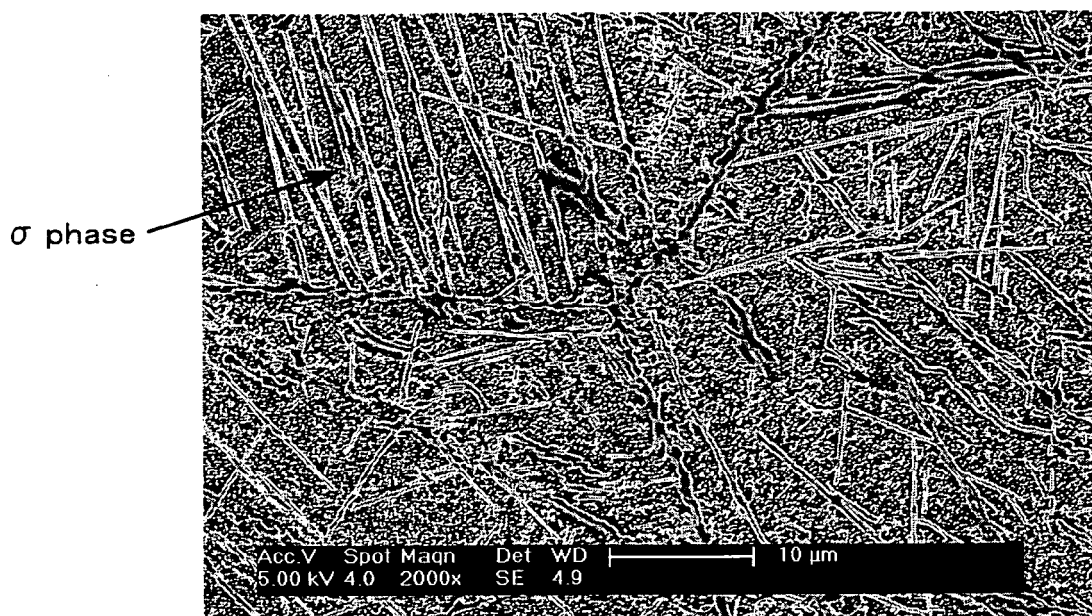
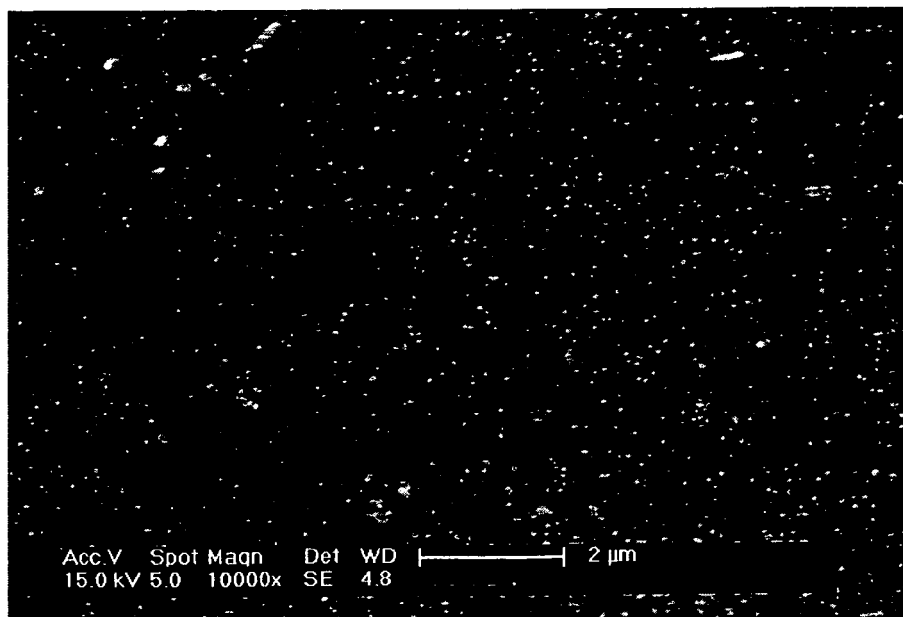


FIG. 4





EUROPEAN SEARCH REPORT

Application Number
EP 10 00 2795

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	EP 0 633 325 A1 (INCO ALLOYS INT [US]) 11 January 1995 (1995-01-11) * the whole document *	1-12	INV. C22C1/02 C22C19/05 C22F1/10 F01D1/00
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			TECHNICAL FIELDS SEARCHED (IPC)
			C22C C22F F01D
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 28 July 2010	Examiner Brown, Andrew
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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28-07-2010

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