(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 806 047 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
26.11.2014 Bulletin 2014/48

(21) Application number: **14169160.0**

(22) Date of filing: **20.05.2014**

(51) Int Cl.:
C22C 38/02 (2006.01) ***C22C 38/04*** (2006.01)
C22C 38/06 (2006.01) ***C22C 38/42*** (2006.01)
C22C 38/44 (2006.01) ***C22C 38/46*** (2006.01)
C22C 38/48 (2006.01) ***C22C 38/50*** (2006.01)
C22C 38/54 (2006.01) ***C21D 6/00*** (2006.01)
C21D 6/02 (2006.01) ***C22C 19/05*** (2006.01)
C22F 1/10 (2006.01)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(30) Priority: **21.05.2013 JP 2013106957**
28.02.2014 JP 2014039222

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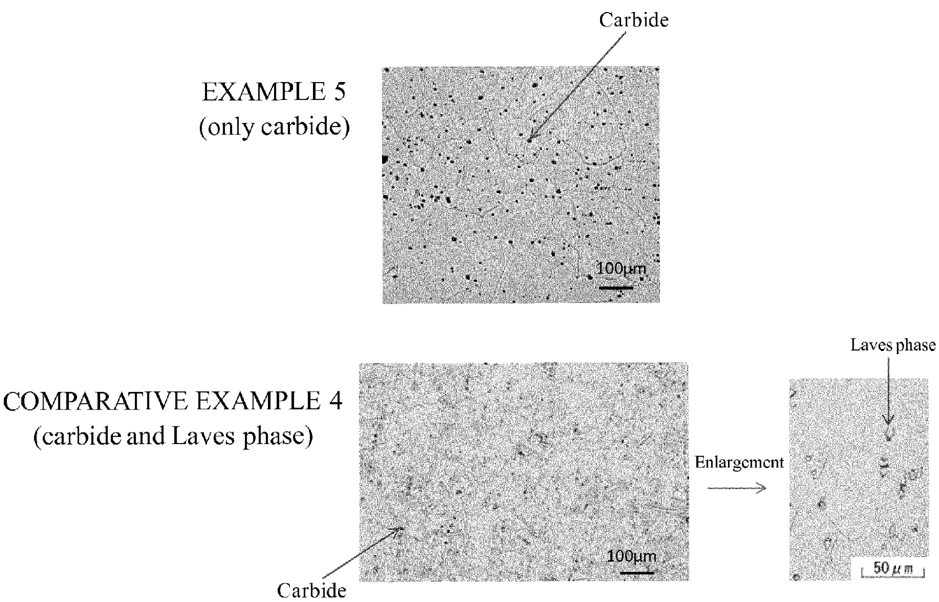
(54) **Precipitation hardened FE-NI alloy**

(57) Provided is a precipitation hardened Fe-Ni alloy having the following constitutions: (1) the precipitation hardened Fe-Ni alloy including: from 0.01 to 0.08% by mass of C, from 0.02 to 1.0% by mass of Si, not more than 1.0% by mass of Mn, from 36.0 to 41.0% by mass of Ni, 14.0 or more and less than 20.0% by mass of Cr, from 0.01 to 3.0% by mass of Mo, from 0.1 to 1.0% by mass of Al, from 1.0 to 2.5% by mass of Ti, and from 2.0 to 3.5% by mass of Nb, with the balance being Fe and unavoidable impurities; (2) the precipitation hardened Fe-Ni alloy satisfying the following formulae: Ni≥6×Nb+17 and Nb/(Ti+Al)0.8.

Fig. 1



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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a precipitation hardened Fe-Ni alloy. More specifically, the invention relates to a precipitation hardened Fe-Ni alloy having high strength and excellent corrosion resistance.

BACKGROUND OF THE INVENTION

[0002] A precipitation hardened stainless steel is a steel in which elements such as Cu, Al, Ti, Nb, and Mo are added to achieve precipitation hardening and has both of high corrosion resistance and high strength. Particularly, an austenite precipitation hardened stainless steel represented by A286 alloy (SUH660) is an alloy excellent in both of corrosion resistance and strength among Fe based alloys. However, for using the austenite precipitation hardened stainless steel as a member requiring high strength in marine environment, it is insufficient in both of corrosion resistance and strength.

[0003] On the other hand, in Fe-Ni alloys, alloys to which Ti, Al, and Nb are added have been hitherto proposed.

[0004] For example, Patent Document 1 (Example 1) discloses a nickel-iron based alloy comprising, in terms of % by weight, 0.027% of C, 0.08% of Mn, 0.10% of Si, 0.001% of P, 0.005% of S, 15.81% of Cr, 39.89% ofNi, 2.83% of Nb, 1.61% of Ti, 0.3% of Al, and 0.0041 % of B, with the balance being Fe and unavoidable impurities.

[0005] Patent Document 2 (No. 1) discloses an Ni based alloy comprising, in terms of % by weight, 0.017% of C, 0.15% of Si, 0.14% of Mn, 0.010% of P, 0.003% of S, 40.32% ofNi, 16.20% of Cr, 1.02% of Mo, 0.25% of Al, 0.95% of Ti, and 2.71% of Nb, with the balance being Fe and unavoidable impurities.

[0006] The document describes a fact that the alloy has high strength from room temperature till extremely low temperature and can suppress HAZ cracking by such a composition.

[0007] Furthermore, Patent Document 3 (alloy #7) discloses a high-strength corrosion-resistant alloy comprising, in terms of % by weight, 44.2% of Ni, 19.5% of Cr, 3.4% of Mo, 2.0% of Cu, 0.006% of C, 0.3% of Al, 3.8% ofNb, and 1.6% of Ti, with the balance being Fe.

[0008] The document describes a fact that high strength is obtained by precipitating predetermined amounts of the y' phase and the y" phase by annealing and aging treatments.

[0009] In Patent Document 1, Mo and Cu are not added and corrosion resistance is insufficient. In Patent Document 2, strength is insufficient owing to the balance among Ni, Nb, Ti, and Al. In Patent Document 3, strength of Ni and Nb are high and the raw material costs and the production costs thereof are high.

[Patent Document 1] JP-A-47-042414
[Patent Document 2] JP-A-03-097823
[Patent Document 3] JP-T-2009-515053 (the term "JP-T" as used herein means a published Japanese translation of a PCT patent application)

SUMMARY OF THE INVENTION

[0010] A problem to be solved by the present invention is to provide a precipitation hardened Fe-Ni alloy having both of high corrosion resistance and high hardness.

[0011] In order to solve the above problem, the gist of the invention is that the precipitation hardened Fe-Ni alloy according to the invention has the following constitutions.

(1) the precipitation hardened Fe-Ni alloy comprising:

from 0.01 to 0.08% by mass of C,
from 0.02 to 1.0% by mass of Si,
not more than 1.0% by mass of Mn,
from 36.0 to 41.0% by mass of Ni,
14.0 or more and less than 20.0% by mass of Cr,
from 0.01 to 3.0% by mass of Mo,
from 0.1 to 1.0% by mass of Al,
from 1.0 to 2.5% by mass of Ti, and
from 2.0 to 3.5% by mass of Nb,
with the balance being Fe and unavoidable impurities;

(2) the precipitation hardened Fe-Ni alloy satisfying the following formulae (1) and (2):

$$Ni \geq 6 \times Nb + 17 \quad (1)$$

$$Nb/(Ti+Al) \geq 0.8 \quad (2).$$

[0012] It is preferred that the precipitation hardened Fe-Ni alloy satisfies the following formula (3):

$$Cr+3Mo+5Cu \geq 19 \quad (3).$$

[0013] When predetermined amounts of Nb, Al, and Ti are added to a precipitation hardened Fe-Ni alloy, the y' phase (Ni_3(Al, Ti, Nb)) and the y" phase (Ni_3Nb) containing Nb as a constituent element are precipitated by a solution heat treatment and an aging treatment.

[0014] At this time, when the Nb content is optimized so as to satisfy the formula (2), the precipitation amount of the y" phase is increased. Therefore, high strength can be obtained as compared with the conventional alloys.

[0015] On the other hand, as the addition amount of Nb increases, the Laves phase (Fe_2Nb) is prone to remain after the solution heat treatment. When the Laves phase remains in a large amount, the Nb amount necessary for precipitation hardening in the matrix decreases. As a result, necessary hardness cannot be obtained even when the aging treatment is performed.

[0016] Contrarily, when the Ni content is optimized so as to satisfy the formula (1), the remaining of the Laves phase can be suppressed after the solution heat treatment.

[0017] Furthermore, when predetermined amounts of Cr and Mo are added to the precipitation hardened Fe-Ni alloy or predetermined amounts of Cr, Mo and Cu are added to the precipitation hardened Fe-Ni alloy, high corrosion resistance is obtained with maintaining high strength. Particularly, when the contents of Cr, Mo and Cu are optimized so as to satisfy the formula (3), high corrosion resistance is obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Fig. 1 shows optical microscopic pictures of the materials after a solution heat treatment obtained in Example 5 and Comparative Example 4.

DETAILED DESCRIPTION OF THE INVENTION

[0019] The following will describe one embodiment of the invention in detail.

[1. Precipitation Hardened Fe-Ni Alloy]

[1.1. Main Constituent Elements]

[0020] The precipitation hardened Fe-Ni alloy according to the invention contains the following elements, with the balance being Fe and unavoidable impurities. Kinds of the addition elements, composition ranges thereof, and reasons for the limitation thereof are as follows.

(1) C: from 0.01 to 0.08% by mass

[0021] C is an element effective for forming a carbide together with Nb and Ti to enhance the strength. Moreover, it suppresses crystal grain coarsening at a solution heat treatment. For obtaining such effects, the C content is necessarily 0.01% by mass or more. The C content is further preferably 0.04% by mass or more.

[0022] On the other hand, when the C content becomes excessive, toughness and ductility are lowered. Moreover, when a large amount of the carbide is formed, corrosion resistance is remarkably lowered. For suppressing the lowering of the toughness and ductility and the corrosion resistance, the C content is necessarily 0.08% by mass or less. The C content is preferably 0.07% by mass or less.

(2) Si: from 0.02 to 1.0% by mass

[0023] Si is effective as a deoxidizing element at the time of ingoting. For obtaining such an effect, the Si content is necessarily 0.02% by mass or more.

[0024] On the other hand, when the Si content becomes excessive, the toughness is lowered. Therefore, the Si content is necessarily 1.0% by mass or less.

(3) Mn: not more than 1.0% by mass

[0025] Similarly to Si, Mn is effective as a deoxidizing element at the time of ingoting. However, when a large amount thereof is added, oxidation resistance at a high temperature is lowered. Moreover, excessive Mn also lowers corrosion resistance. Therefore, the Mn content is necessarily 1.0% by mass or less.

(4) Ni: from 36.0 to 41.0% by mass

[0026] Ni is essential as an austenite-forming element. Also, Ni makes the alloy age-hardened through precipitation of the y' phase (Ni_3(Al, Ti, Nb)) and the y" phase (Ni_3Nb) together with Ti, Al, and Nb by the aging treatment. For obtaining such an effect, the Ni content is necessarily 36.0% by mass or more. The Ni content is more preferably 37.0% by mass or more.

[0027] On the other hand, when the Ni content becomes excessive, the raw material costs are increased. Therefore, the Ni content is necessarily 41.0% by mass or less. The Ni content is more preferably 40.0% by mass or less, further preferably 39.0% by mass or less.

(5) Cr: 14.0 or more and less than 20.0% by mass

[0028] Cr is an inevitable component for enhancing the corrosion resistance of the precipitation hardened Fe-Ni alloy. For obtaining such an effect, the Cr content is necessarily 14.0% by mass or more.

[0029] However, Cr is a ferrite-forming element and, when the Cr content becomes excessive, structural stability is lowered. Also, excessive Cr lowers hot workability. Therefore, the Cr content is necessarily less than 20.0% by mass. The Cr content is more preferably 18.0% by mass or less, further preferably 17.0% by mass or less.

(6) Mo: from 0.01 to 3.0% by mass

[0030] Mo improves the corrosion resistance (particularly pitting resistance) through solution into the parent phase. For obtaining such an effect, the Mo content is necessarily 0.01 % by mass or more.

[0031] On the other hand, when the Mo content becomes excessive, the Laves phase (Fe_2(Mo, Nb)) is precipitated at the time of the aging treatment and the precipitation amounts of the y' phase and the y" phase are decreased. As a result, the strength of the alloy is lowered. Therefore, the Mo content is necessarily 3.0% by mass or less. The Mo content is preferably 2.0% by mass or less.

(7) Al: from 0.1 to 1.0% by mass

[0032] Al makes the alloy age-hardened through precipitation of the y' phase (Ni_3(Al, Ti, Nb)) together with Ni, Ti, and Nb. For obtaining such an effect, the Al content is necessarily 0.1% by mass or more.

[0033] When the Al content becomes excessive, the hot workability is lowered. Therefore, the Al content is necessarily 1.0% by mass or less. The Al content is preferably 0.5% by mass or less.

(8) Ti: from 1.0 to 2.5% by mass

[0034] Ti makes the alloy age-hardened through precipitation of the y' phase (Ni_3(Al, Ti, Nb)) together with Ni, Al, and Nb. For obtaining such an effect, the Ti content is necessarily 1.0% by mass or more. The Ti content is preferably 1.5% by mass or more, more preferably 1.8% by mass or more.

[0035] On the other hand, when the Ti content becomes excessive, the hot workability is lowered. Therefore, the Ti content is necessarily 2.5% by mass or less.

(9) Nb: from 2.0 to 3.5% by mass

[0036] Nb makes the alloy age-hardened through precipitation of the y' phase (Ni_3(Al, Ti, Nb)) and the y" phase (Ni_3Nb) together with Ni. For obtaining such an effect, the Nb content is necessarily 2.0% by mass or more.

[0037] On the other hand, when the Nb content becomes excessive, a coarse Laves phase remains after the solution heat treatment and the precipitation amounts of the y' phase and the y" phase are decreased. As a result, required strength and hardness are not obtained. Therefore, the Nb content is necessarily 3.5% by mass or less. The Nb content is more preferably 3.0% by mass or less.

[1.2. Auxiliary Constituent Elements]

[0038] The precipitation hardened Fe-Ni alloy according to the invention may further contain one kind or two or more kinds of the following auxiliary constituent elements in addition to the aforementioned main constituent elements. Kinds of the addition elements, composition ranges thereof, and reasons for the limitation thereof are as follows.

(10) B: from 0.0005 to 0.01% by mass

[0039] B has an effect of enhancing the hot workability by adding B in a small amount. Also, the precipitation of the η phase at a grain boundary can be suppressed by the presence of B at the grain boundary. For obtaining such an effect, the B content is preferably 0.0005% by mass or more. The B content is further preferably 0.0010% by mass or more. The B content is particularly preferably 0.0020% by mass or more.
[0040] On the other hand, when the Ni content becomes excessive, the hot workability is lowered. Therefore, the B content is preferably 0.01% by mass or less. The B content is further preferably 0.008% by mass or less.

(11) Cu: from 0.05 to 1.0% by mass

[0041] Cu has an effect of enhancing the corrosion resistance in a non-oxidative corrosive environment. For obtaining such an effect, the Cu content is preferably 0.05% by mass or more. The Cu content is further preferably 0.10% by mass or more.
[0042] On the other hand, when the Cu content becomes excessive, the hot workability is lowered. Therefore, the Cu content is preferably 1.0% by mass or less.

(12) V: from 0.05 to 1.0% by mass

[0043] As is the case with Nb and Ti, V forms a carbide to enhance the strength. Also, the precipitation amounts of the γ' phase and the γ" phase are increased through reducing the ratio of Nb in the carbide. For obtaining such effects, the V content is preferably 0.05% by mass or more.
[0044] On the other hand, when the V content becomes excessive, the toughness and the processability are lowered. Therefore, the V content is preferably 1.0% by mass or less.

(13) Zr, Ta, W, Hf, Mg, and/or REM: from 0.001 to 0.50% by mass

[0045] Zr, Ta, W, Hf, Mg, and REM (Rare Earth Metal) have an effect on micronization of the carbide and micronization of crystal grains. For obtaining such an effect, a total content of these elements is preferably 0.001% by mass or more.
[0046] On the other hand, when the content of these elements becomes excessive, the toughness is lowered. Therefore, the total content of these elements is preferably 0.50% by mass or less.
[0047] Incidentally, any one of these elements may be added or two or more thereof may be used in combination.

(14) Ca: from 0.0005 to 0.01% by mass

[0048] Ca improves machinability. For obtaining such an effect, the Ca content is preferably 0.0005% by mass or more.
[0049] On the other hand, when the Ca content becomes excessive, the hot workability is lowered. Therefore, the Ca content is preferably 0.01% by mass or less.

[1.3. Component Balance]

[0050] The precipitation hardened stainless steel according to the invention necessarily satisfies the following formulae (1) and (2), in addition to the requirement that the constituent elements are present in the aforementioned ranges.
[0051] Moreover, for obtaining high corrosion resistance, the precipitation hardened stainless steel preferably further satisfies the following formula (3).

$$Ni \geq 6 \times Nb + 17 \quad ... (1)$$

$$Nb/(Ti+Al) \geq 0.8 \quad ... (2)$$

$$Cr+3Mo+5Cu \geq 19 \quad ... (3)$$

[1.3.1. Formula (1)]

[0052] The formula (1) is relevant to the amount of the Laves phase after the solution heat treatment. When the Ni amount and the Nb amount are optimized so as to satisfy the formula (1), the Laves phase (Fe_2Nb) can be completely dissolved after the solution heat treatment. As a result, the precipitation amounts of the y' phase and the y" phase at the time of the aging treatment are increased and thereby the strength of the alloy is enhanced.
[0053] The formula (1) is more preferably Ni≥6xNb+18.0, further preferably Ni≥6xNb+20.0.

[1.3.2. Formula (2)]

[0054] The formula (2) is relevant to the amount of the y" phase at the time of the aging treatment. When the amounts of Nb, Ti, and Al are optimized so as to satisfy the formula (2), the precipitation amount of the y" phase is increased and thereby further enhancing the strength of the alloy.

[1.3.3. Formula (3)]

[0055] The formula (3) is relevant to the corrosion resistance of the precipitation hardened Fe-Ni alloy. Cr, Mo, and Cu all have an effect of enhancing the corrosion resistance of the precipitation hardened Fe-Ni alloy. Particularly, when the contents of these elements are optimized so as to satisfy the formula (3), high corrosion resistance is exhibited with maintaining high strength.

[1.4.0.2% Offset Yield Strength]

[0056] When individual components are optimized as mentioned above and a suitable solution heat treatment is performed, the Laves phase is almost completely dissolved in the matrix. When such a material is subjected to a suitable aging treatment, large amounts of the y' phase and the y" phase are precipitated. As a result, the 0.2% offset yield strength at room temperature becomes 850 MPa or more. When the components and the heat treatment conditions are further optimized, the 0.2% offset yield strength at room temperature becomes 900 MPa or more or 950 MPa or more.

[1.5. Area Percentage of Carbide]

[0057] The precipitation hardened Fe-Ni alloy according to the invention is preferably one in which an area percentage of the carbide after the solution heat treatment is 0.4% or more. At the time of the solution heat treatment, the coarsening of crystal grains can be suppressed when a predetermined amount of the carbide is dispersed in the matrix.
[0058] Here, the "area percentage of the carbide" means a ratio of area of the carbide to the total area of cross-sectional microstructure (0.034 mm^2 x 30 viewing fields).

[2. Method for Manufacturing Precipitation Hardened Fe-Ni Alloy]

[0059] The method for manufacturing the precipitation hardened Fe-Ni alloy according to the invention comprises a melting and casting process, a hot working process, a solution heat treatment process, and an aging treatment process.

[2.1. Melting and Casting Process]

[0060] The melting and casting process is a process of dissolving a raw material blended in a predetermined composition and performing casting. The dissolving method and the casting method are not particularly limited and various methods can be used according to the purpose.

[2.2. Hot Working Process]

[0061] The hot working process is a process of hot-working an ingot obtained in the melting and casting process. The hot working is performed for destroying cast structure and casting defect. Hot working conditions are not particularly limited and most suitable conditions can be selected according to the purpose.

[2.3. Solution Heat Treatment Process]

[0062] The solution heat treatment process is a process of heating a hot-worked material at a predetermined temperature.

[0063] The solution heat treatment is performed mainly for dissolving a precipitate dispersed in the steel. When heat treatment temperature is too low, solution of the precipitate becomes insufficient. The heat treatment temperature is preferably 900°C or higher.

[0064] On the other hand, when the heat treatment temperature is too high, the crystal grains are coarsened. The heat treatment temperature is preferably 1,200°C or lower.

[0065] Heat treatment time may be suitably a time sufficient for dissolving the precipitate. Most suitable heat treatment time varies depending on the heat treatment temperature but is usually from about 30 minutes to about 2 hours. After the heat treatment, the material is quenched.

[2.4. Aging Treatment Process]

[0066] The aging treatment process is a process of subjecting the material after the solution heat treatment to an aging treatment at a predetermined temperature.

[0067] In both cases where aging treatment temperature is too high and too low, an objective precipitate is not precipitated and aging hardening cannot be achieved. The aging treatment temperature is preferably from 600°C to 750°C.

[0068] Aging treatment time may be suitably a time sufficient for precipitating a sufficient amount of the precipitate. Most suitable aging treatment time varies depending on the aging treatment temperature but is usually from about 8 hours to about 24 hours.

[3. Action]

[0069] When a predetermined amount of Nb is added to the precipitation hardened Fe-Ni alloy, the y' phase (Ni_3(Al, Ti, Nb)) and the y" phase (Ni_3Nb) containing Nb as a constituent element are precipitated by the solution heat treatment and the aging treatment.

[0070] At this time, when the Nb content is optimized so as to satisfy the formula (2), the precipitation amount of the y" phase is increased. Therefore, as compared with conventional alloys, high strength can be obtained.

[0071] On the other hand, as the addition amount of Nb increases, the Laves phase (Fe_2Nb) tends to remain after the solution heat treatment. When a large amount of the Laves phase remains, the Nb amount in the matrix necessary for precipitation hardening decreases. As a result, necessary hardness is not obtained even when the aging treatment is performed.

[0072] In contrast, when the Ni content is optimized so as to satisfy the formula (1), the remaining of the Laves phase after the solution heat treatment can be suppressed.

[0073] Furthermore, when predetermined amounts of Cr and Mo are added to the precipitation hardened Fe-Ni alloy or predetermined amounts of Cr, Mo and Cu are added to the precipitation hardened Fe-Ni alloy, high corrosion resistance is obtained with maintaining high strength. Particularly, when the contents of Cr, Mo, and Cu are optimized so as to satisfy the formula (3), high corrosion resistance is obtained.

EXAMPLES

(Examples 1 to 37, Comparative Examples 1 to 5)

[1. Preparation of Samples]

[0074] After each steel containing various components shown in Tables 1 and 2 was ingoted, each steel was cooled to prepare an ingot. After hot working, the ingot was thermally refined by a solution heat treatment and an aging treatment.

[0075] Solution heat treatment temperature was set to 900 to 1,200°C. Also, the aging treatment temperature was set to 600 to 750°C.

Table 1

	Component composition (% by mass)												Component balance		
	C	Si	Mn	Ni	Cr	Mo	Al	Ti	Nb	B	Cu	V	Others	Formula (1')	Formula (2')	Formula (3')
Example 1	0.06	0.24	0.1	39.2	15.7	0.01	0.2	1.9	3.1	-		-		3.6	0.68	-3.27
Example 2	0.05	0.41	0.5	36.9	15.4	0.03	0.2	2.3	2.7	0.0051	0.07	-		3.7	0.28	-3.16
Example 3	0.06	0.46	0.3	39.8	15.8	0.13	0.5	2.1	3.2	0.0099	0.06	-		3.6	0.43	-2.51
Example 4	0.04	0.35	0.3	39.8	15.4	1.54	0.3	2.4	2.7	0.0041	0.07	-		6.6	0.20	1.37
Example 5	0.04	0.35	0.3	39.8	15.4	0.52	0.3	2.4	2.7	0.0025	0.07	-		6.6	0.20	-1.69
Example 6	0.05	0.39	0.6	36.8	15.0	2.40	0.2	2.2	2.7	0.0046	0.06	-		3.6	0.33	3.50
Example 7	0.04	0.35	0.3	41.0	15.4	1.54	0.3	2.2	2.7	0.0063	0.07	-		7.8	0.28	1.37
Example 8	0.04	0.35	0.3	38.9	15.4	0.53	0.3	2.2	2.7	0.0006	0.52	-		5.7	0.28	0.59
Example 9	0.04	0.35	0.3	38.9	15.4	0.52	0.3	2.2	2.7	0.0051	0.07	0.5		5.7	0.28	-1.69
Example 10	0.04	0.35	0.3	38.9	17.8	0.52	0.3	2.2	2.7	0.0099	0.07	-		5.7	0.28	0.71
Example 11	0.04	0.35	0.3	38.9	19.5	0.52	0.3	2.2	2.7	0.0041	0.07	-		5.7	0.28	2.41
Example 12	0.04	0.35	0.3	36.4	15.4	0.52	0.3	2.2	2.7	0.0025	0.07	-		3.2	0.28	-1.69
Example 13	0.04	0.35	0.3	38.9	15.4	0.52	0.3	2.2	2.2	0.0046	0.07	-		8.7	0.08	-1.69
Example 14	0.04	0.35	0.3	38.9	15.4	0.52	0.3	2.2	3.4	0.0063	0.07	-		1.5	0.56	-1.69
Example 15	0.04	0.35	0.3	38.9	15.4	0.52	0.9	2.2	2.7	0.0006	0.07	-		5.7	0.07	-1.69
Example 16	0.04	0.35	0.3	38.9	15.4	0.52	0.3	1.3	2.7	0.0051	0.07	-		5.7	0.89	-1.69
Example 17	0.04	0.35	0.3	38.9	15.4	0.52	0.3	2.4	2.7	0.0099	0.07	-		5.7	0.20	-1.69
Example 18	0.04	0.82	0.3	38.9	15.4	0.52	0.3	2.2	2.7	0.0041	0.07	-	Zr:0.05	5.7	0.28	-1.69
Example 19	0.04	0.35	0.3	38.9	15.4	0.52	0.3	2.2	2.7	0.0025	0.07	-	Ta:0.15	5.7	0.28	-1.69
Example 20	0.04	0.35	0.3	38.9	15.4	0.52	0.3	2.2	2.7	0.0046	0.07	-	W:0.32	5.7	0.28	-1.69
Example 21	0.04	0.35	0.3	38.9	15.4	0.52	0.3	2.2	2.7	0.0063	0.07	-	Hf:0.21	5.7	0.28	-1.69

* Formula (1') = Ni-(6xNb+17) Formula (2') = Nb/(Ti+Al)-0.8, Formula (3') = Cr+3Mo+5Cu-19

Table 2

	Component composition (% by mass)													Component balance		
	C	Si	Mn	Ni	Cr	Mo	Al	Ti	Nb	B	Cu	V	Others	Formula (1')	Formula (2')	Formula (3')
Example 22	0.04	0.35	0.3	38.9	15.4	0.52	0.3	2.2	2.7	0.0006	0.07	-	Mg:0.02	5.7	0.28	-1.69
Example 23	0.04	0.35	0.3	38.9	15.4	0.52	0.3	2.2	2.7	0.0046	0.07	-	REM:0.03	5.7	0.28	-1.69
Example 24	0.04	0.35	0.3	38.9	15.4	0.52	0.3	2.2	2.7	0.0063	0.07	-	Ca:0.004	5.7	0.28	-1.69
Example 25	0.04	0.35	0.3	38.9	15.4	1.62	0.3	2.2	2.7	0.0006	0.61	-		5.7	0.28	4.31
Example 26	0.04	0.35	0.3	38.0	15.7	0.01	0.2	2.2	2.7	0.0011		-		4.8	0.33	-3.27
Example 27	0.04	0.35	0.3	38.0	15.4	0.03	0.3	2.4	2.5	0.0023		-		6.0	0.13	-3.51
Example 28	0.04	0.35	0.6	38.0	15.8	0.13	0.2	2.2	2.7	0.0005	0.36	-		4.8	0.33	-1.01
Example 29	0.04	0.35	0.5	38.0	15.4	1.54	0.3	2.2	2.5	0.0042	0.09	-		6.0	0.20	1.47
Example 30	0.04	0.24	0.4	38.0	15.4	0.52	0.2	2.2	2.7	0.0051		-		4.8	0.33	-2.04
Example 31	0.04	0.24	0.5	38.0	17.8	0.53	0.3	2.2	2.5	0.0048		-		6.0	0.20	0.39
Example 32	0.05	0.24	0.6	38.0	19.5	0.52	0.2	1.5	2.7	0.0045	0.43	-		4.8	0.79	4.21
Example 33	0.05	0.46	0.3	38.0	15.4	0.52	0.3	2.2	2.5	0.0029	0.05	-		6.0	0.20	-1.79
Example 34	0.05	0.46	0.3	38.0	15.4	0.51	0.2	2.2	2.7	0.0055		0.3		4.8	0.33	-2.07
Example 35	0.05	0.46	0.3	38.0	15.6	0.51	0.3	2.2	2.5	0.0061		0.4		6.0	0.20	-1.87
Example 36	0.05	0.46	0.3	38.0	15.8	0.52	0.2	2.2	2.7	0.0053	0.57	0.4		4.8	0.33	1.21
Example 37	0.05	0.46	0.3	38.0	15.9	0.52	0.3	2.2	2.5	0.0048		0.5		6.0	0.20	-1.54
Comparative Example 1	0.03	0.31	0.2	25.1	15.0	1.1	0.2	2.2	-	-		0.3				
Comparative Example 2	0.04	0.35	0.3	33.8	15.4	0.52	0.3	2.2	2.7	0.0041	0.07	-		0.6	0.28	-1.69
Comparative Example 3	0.04	0.35	0.3	36.3	15.4	0.52	0.5	2.2	2.0	0.0041	0.07	-		7.3	-0.06	-1.69
Comparative Example 4	0.04	0.35	0.3	36.3	15.4	0.52	0.3	2.2	3.4	0.0041	0.07	-		-1.1	0.56	-1.69
Comparative Example 5	0.03	0.35	0.3	38.9	15.4	0.53	0.3	2.2	2.7	0.0045	0.07	-		5.7	0.28	-1.66

* Formula (1') = Ni-(6xNb+17), Formula (27) = Nb/(Ti+Al)-0.8, Formula (3') = Cr+3Mo+5Cu-19

[2. Test Methods]

[2.1. Tensile Test]

[0076] From each material after the aging treatment, a JIS No. 4 test piece was cut out. A tensile test was performed at room temperature (20°C) to evaluate tensile strength and 0.2% offset yield strength.

[2.2. Corrosion Resistance Test]

[0077] Evaluation of the corrosion resistance was performed on a corrosion rate at the time of immersion for 6 h in 10% hydrochloric acid at 80°C. The case where the corrosion rate was 100 $g/m^2/h$ or less was designated as "A", the case where the rate was more than 100 $g/m^2/h$ and 200 $g/m^2/h$ or less was designated as "B", and the case where the rate was more than 200 $g/m^2/h$ was designated as "C".

[2.3. Carbide Area Percentage]

[0078] For quantitative analysis of a carbide, area percentage was measured at 30 visual fields on a microstructure photograph with a magnification of 400 times (1 visual field: 0.034 mm^2) using an image-analyzing software.

[3. Results]

[0079] Table 3 shows results. From Table 3, the following are realized.

(1) In Comparative Example 1 (corresponding to A286 alloy), the tensile strength and the 0.2% offset yield strength are low. This is because Nb is not added and the y" phase is not precipitated. Also, in Comparative Example 1, the corrosion resistance is low. This is because the Ni amount is small.
(2) In Comparative Example 2, the 0.2% offset yield strength is slightly low. This is because the Ni content is small and hence a sufficient amount of the y" phase is not obtained. Also, in Comparative Example 2, the corrosion resistance is low. This is because the Ni amount is small.
(3) In Comparative Example 3, the 0.2% offset yield strength is slightly low. This is because a sufficient amount of the y" phase is not obtained owing to a low value of Nb/(Ti+Al)-0.8.
(4) In Comparative Example 4, the 0.2% offset yield strength is slightly low. This is because a coarse Laves phase remains owing to a low value of Ni-(6xNb+17) and, as a result, the Nb amount in the matrix is decreased and hence the precipitation amounts of the y' phase and the y" phase at the time of the aging treatment are decreased.
(5) In Comparative Example 5, the 0.2% offset yield strength is slightly low. This is because the crystal grains are coarsened owing to the small carbide area percentage, i.e., the small amount of the carbide which suppresses crystal grain coarsening at the time of the solution heat treatment.
(6) In all of Examples 1 to 37, the 0.2% offset yield strength is more than 850 MPa and good corrosion resistance is exhibited.
(7) Among Examples, the materials satisfying the formula (3) particularly exhibit high corrosion resistance.

Table 3

	Tensile strength (MPa)	0.2% offset yield strength (MPa)	Corrosion resistance	Carbide area percentage (%)
Example 1	1168	972	B	0.73
Example 2	1160	929	B	0.68
Example 3	1191	990	B	0.74
Example 4	1153	961	A	0.51
Example 5	1196	946	B	0.53
Example 6	1137	894	A	0.59
Example 7	1163	972	A	0.48
Example 8	1160	969	A	0.49

(continued)

	Tensile strength (MPa)	0.2% offset yield strength (MPa)	Corrosion resistance	Carbide area percentage (%)
Example 9	1193	945	B	0.54
Example 10	1162	931	A	0.50
Example 11	1142	924	A	0.55
Example 12	1132	866	B	0.52
Example 13	1175	888	B	0.47
Example 14	1227	997	B	0.61
Example 15	1197	948	B	0.45
Example 16	1173	857	B	0.41
Example 17	1206	937	B	0.60
Example 18	1198	948	B	0.52
Example 19	1187	936	B	0.54
Example 20	1203	952	B	0.53
Example 21	1193	942	B	0.58
Example 22	1186	941	B	0.51
Example 23	1188	937	B	0.54
Example 24	1192	945	B	0.49
Example 25	1137	894	A	0.55
Example 26	1152	963	B	0.53
Example 27	1163	984	B	0.58
Example 28	1155	966	A	0.42
Example 29	1148	957	B	0.47
Example 30	1166	987	B	0.54
Example 31	1152	964	A	0.61
Example 32	1141	887	A	0.68
Example 33	1159	989	B	0.72
Example 34	1164	977	B	0.71
Example 35	1161	983	B	0.66
Example 36	1142	850	A	0.65
Example 37	1172	887	B	0.69
Comparative Example 1	1052	651	C	0.35
Comparative Example 2	1166	850	C	0.53
Comparative Example 3	1004	843	C	0.52
Comparative Example 4	1018	827	C	0.55

(continued)

	Tensile strength (MPa)	0.2% offset yield strength (MPa)	Corrosion resistance	Carbide area percentage (%)
Comparative Example 5	1115	846	B	0.38

[0080] Fig. 1 shows optical microscopic photographs of materials after solution heat treatment obtained in Example 5 and Comparative Example 4. From Fig. 1, it is realized that the Laves phase is observed besides the carbide in Comparative Example 4 but the Laves phase is not observed in Example 5.

[0081] While the mode for carrying out the present invention has been described in detail above, the present invention is not limited to these embodiments, and various changes and modifications can be made therein without departing from the purport of the present invention.

[0082] This application is based on Japanese patent application No. 2013-106957 filed May 21, 2013 and Japanese patent application No. 2014-039222 filed February 28, 2014, the entire contents thereof being hereby incorporated by reference.

INDUSTRIAL APPLICABILITY

[0083] The precipitation hardened Fe-Ni alloy according to the invention can be used as members for excavation, automobile engine parts, thermal power generation plant members, and the like.

Claims

1. A precipitation hardened Fe-Ni alloy having the following constitutions:

(1) the precipitation hardened Fe-Ni alloy comprising:

from 0.01 to 0.08% by mass of C,
from 0.02 to 1.0% by mass of Si,
not more than 1.0% by mass of Mn,
from 36.0 to 41.0% by mass of Ni,
14.0 or more and less than 20.0% by mass of Cr,
from 0.01 to 3.0% by mass of Mo,
from 0.1 to 1.0% by mass of Al,
from 1.0 to 2.5% by mass of Ti, and
from 2.0 to 3.5% by mass of Nb,
with the balance being Fe and unavoidable impurities;

(2) the precipitation hardened Fe-Ni alloy satisfying the following formulae (1) and (2):

$$Ni \geq 6 \times Nb + 17 \qquad (1)$$

$$Nb/(Ti+Al) \geq 0.8 \qquad (2).$$

2. The precipitation hardened Fe-Ni alloy according to claim 1, further comprising from 0.0005 to 0.01% by mass of B.

3. The precipitation hardened Fe-Ni alloy according to claim 1 or 2, wherein an area percentage of a carbide after a solution heat treatment is 0.4% or more.

4. The precipitation hardened Fe-Ni alloy according to any one of claims 1 to 3, further comprising from 0.05 to 1.0% by mass of Cu.

5. The precipitation hardened Fe-Ni alloy according to any one of claims 1 to 4, further comprising from 0.05 to 1.0%

by mass of V.

6. The precipitation hardened Fe-Ni alloy according to any one of claims 1 to 5, further comprising at least one element selected from the group consisting of Zr, Ta, W, Hf, Mg, and REM, provided that a total content thereof is from 0.001 to 0.50% by mass.

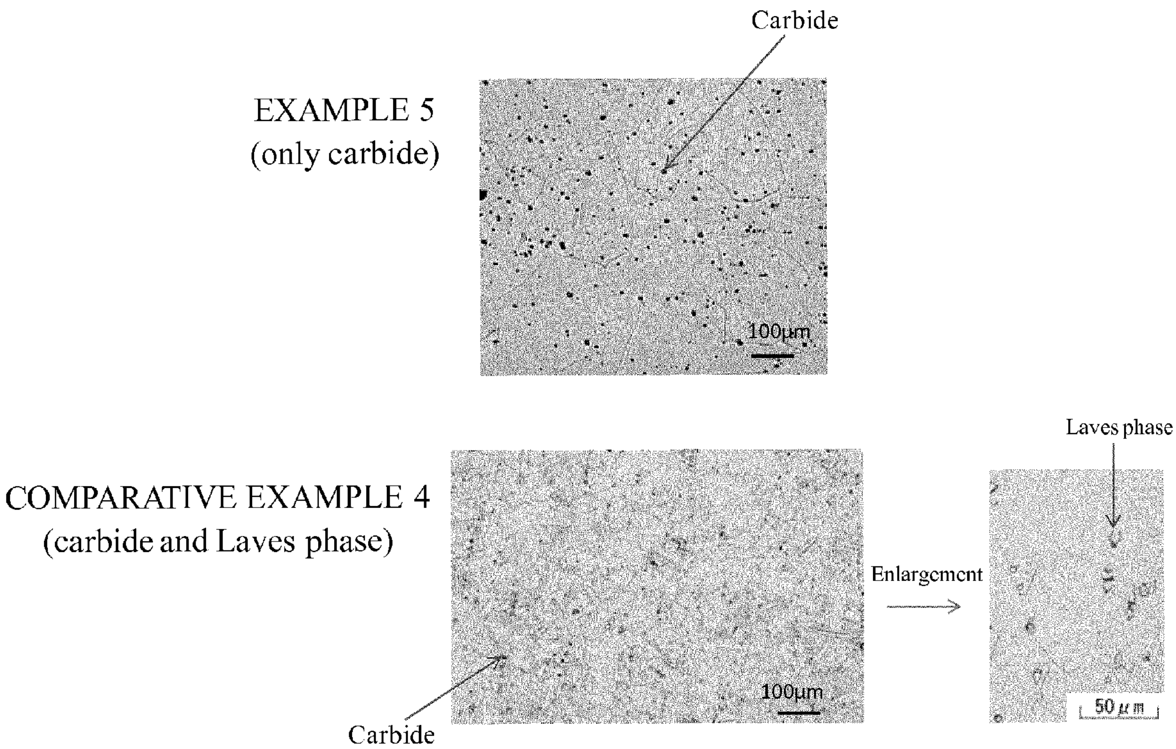
7. The precipitation hardened Fe-Ni alloy according to any one of claims 1 to 6, further comprising from 0.0005 to 0.01% by mass of Ca.

8. The precipitation hardened Fe-Ni alloy according to any one of claims 1 to 7, wherein 0.2% offset yield strength at room temperature is 900 MPa or more.

9. The precipitation hardened Fe-Ni alloy according to any one of claims 1 to 8, further satisfying the following formula (3):

$$Cr+3Mo+5Cu\geq 19 \qquad (3).$$

Fig. 1


Carbide
EXAMPLE 5
(only carbide)
100μm
Laves phase
COMPARATIVE EXAMPLE 4
(carbide and Laves phase)
Enlargement
100μm
50μm
Carbide

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EUROPEAN SEARCH REPORT

Application Number
EP 14 16 9160

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	26 September 2014	Vlassi, Eleni

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EUROPEAN SEARCH REPORT

Application Number
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