



(11)

EP 4 269 642 A1

(12)

EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:

01.11.2023 Bulletin 2023/44

(21) Application number: **21914923.4**

(22) Date of filing: **07.04.2021**

(51) International Patent Classification (IPC):

C22C 38/00 ^(2006.01) **C22C 19/03** ^(2006.01)
C22C 19/05 ^(2006.01) **C22C 38/06** ^(2006.01)
C22C 38/60 ^(2006.01)

(52) Cooperative Patent Classification (CPC):

C22C 19/03; C22C 19/05; C22C 38/00;
C22C 38/06; C22C 38/60

(86) International application number:

PCT/JP2021/014738

(87) International publication number:

WO 2022/145061 (07.07.2022 Gazette 2022/27)

(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

Designated Validation States:

KH MA MD TN

(30) Priority: **28.12.2020 JP 2020218859**

(71) Applicant: **NIPPON STEEL CORPORATION**

Chiyoda-ku

Tokyo 100-8071 (JP)

(72) Inventors:

- **ISHIKAWA, Kyohei**
Tokyo 100-8071 (JP)
- **OGISU, Yasuyuki**
Tokyo 100-8071 (JP)
- **KIMURA, Ken**
Tokyo 100-8071 (JP)
- **UMEHARA, Miyuri**
Tokyo 100-8071 (JP)
- **YAMASAKI, Shingo**
Tokyo 100-8071 (JP)

(74) Representative: **Vossius & Partner**

Patentanwälte Rechtsanwälte mbB
Siebertstraße 3
81675 München (DE)

(54) **STEEL MATERIAL**

(57) Provided is a steel material having a predetermined chemical composition satisfying
 $0.40[\text{Pr}] + 0.37[\text{Sm}] + 0.37[\text{Eu}] + 0.36[\text{Gd}] + 0.35[\text{Tb}] + 0.34[\text{Dy}] + 0.34[\text{Ho}] + 0.33[\text{Er}] + 0.33[\text{Tm}] + 0.3$

$2[\text{Yb}] + 0.32[\text{Lu}] + 1.24[\text{Sc}] - 2.33[\text{O}] - 3.99[\text{N}] - 1.74[\text{S}] \geq 0.0003$ (where [Pr], [Sm], [Eu], [Gd], [Tb], [Dy], [Ho], [Er], [Tm], [Yb], [Lu], [Sc], [O], [N], and [S] are the contents [mass%] of the elements).

EP 4 269 642 A1

Description

FIELD

5 **[0001]** The present invention relates to a steel material.

FIELD

10 **[0002]** To improve the material properties sought from steel materials, it is generally known that refining the metallic structure is effective. In this regard, in the past, to refine the metallic structure, for example, the practice has been to control the end temperature when hot rolling a steel material, more specifically finish rolling it, so as to inhibit recrystallization of the austenite grains and, due to such inhibition of recrystallization, raise the drive force of ferrite transformation and cause the formation of more new crystals (for example, see PTL 1 to PTL 4).

15 **[0003]** PTL 1 teaches that by causing the copresence of B in addition to Nb, the recrystallization temperature of austenite becomes 50°C or more higher and the hardenability is greatly improved resulting in a much greater improvement in the strength/toughness balance compared with the value projected from Nb and B alone. PTLs 2 and 3 describe that Nb causes a rise in the recrystallization temperature, therefore is an element effective for refining the grains of austenite at a high temperature. PTL 4 describes that Nb, in fine amounts, inhibits the recrystallization of austenite and contributes to refinement of the metallic structure.

20

[CITATIONS LIST]

[PATENT LITERATURE]

25 **[0004]**

[PTL 1] Japanese Unexamined Patent Publication No. 58-077528

[PTL 2] Japanese Unexamined Patent Publication No. 63-235430

[PTL 3] Japanese Unexamined Patent Publication No. 63-235431

30 [PTL 4] Japanese Unexamined Patent Publication No. 2004-269924

SUMMARY

[TECHNICAL PROBLEM]

35

[0005] Niobium (Nb) is known to be an element effective for inhibiting recrystallization, but is also an element contributing to improvement of the hardenability and precipitation strengthening. For this reason, if making the content of Nb increase to obtain a higher effect of inhibition of recrystallization, the strength of the obtained steel material becomes too high and sometimes the toughness falls in relation to this. Therefore, in this technical field, there is a need for a steel material containing, in addition to Nb as well, elements having a similar or higher effect of inhibition of recrystallization as Nb according to the applications in which the steel material is used or the properties, etc., sought in those applications.

40

[0006] The present invention was made in consideration of such a situation and has as its object to provide a steel material having an improved effect of inhibition of recrystallization or improved in inhibition of recrystallization by a novel constitution.

45

[SOLUTION TO PROBLEM]

[0007] The inventors studied the elements able to inhibit or retard recrystallization of austenite grains for achieving the above object. As a result, the inventors discovered that by making the amounts of specific elements dissolved in steel increase, it is possible to inhibit or retard recrystallization so as to make the temperature at which recrystallization starts (below, also simply referred to as the "recrystallization start temperature") shift to the high temperature side and thereby completed the present invention.

50

[0008] The steel material able to achieve the above object is as follows:

55

(1) A steel material having a chemical composition consisting of, by mass%,

C: 0.001 to 1.000%,

Si: 0.01 to 3.00%,

Mn: 0.10 to 4.50%,
 P: 0.300% or less,
 S: 0.0300% or less,
 Al: 0.001 to 5.000%,
 N: 0.2000% or less,
 O: 0.0100% or less,

at least one X element selected from the group consisting of Pr: 0 to 0.8000%, Sm: 0 to 0.8000%, Eu: 0 to 0.8000%, Gd: 0 to 0.8000%, Tb: 0 to 0.8000%, Dy: 0 to 0.8000%, Ho: 0 to 0.8000%, Er: 0 to 0.8000%, Tm: 0 to 0.8000%, Yb: 0 to 0.8000%, Lu: 0 to 0.8000%, and Sc: 0 to 0.8000%,

Nb: 0 to 3.000%,
 Ti: 0 to 0.500%,
 Ta: 0 to 0.500%,
 V: 0 to 1.00%,

Cu: 0 to 3.00%,
 Ni: 0 to 60.00%,
 Cr: 0 to 30.00%,
 Mo: 0 to 5.00%,

W: 0 to 2.00%,
 B: 0 to 0.0200%,
 Co: 0 to 3.00%,
 Be: 0 to 0.050%,

Ag: 0 to 0.500%,
 Zr: 0 to 0.5000%,
 Hf: 0 to 0.5000%,
 Ca: 0 to 0.0500%,

Mg: 0 to 0.0500%,
 at least one of La, Ce, Nd, Pm, and Y: 0 to 0.5000% in total,

Sn: 0 to 0.300%,
 Sb: 0 to 0.300%,
 Te: 0 to 0.100%,

Se: 0 to 0.100%,
 As: 0 to 0.050%,
 Bi: 0 to 0.500%,

Pb: 0 to 0.500%, and
 balance: Fe and impurities, and
 satisfying the following formula 1:

$$0.40[\text{Pr}] + 0.37[\text{Sm}] + 0.37[\text{Eu}] + 0.36[\text{Gd}] + 0.35[\text{Tb}] + 0.34[\text{Dy}] + 0.34[\text{Ho}] + 0.33[\text{Er}] + 0.33[\text{Tm}] + 0.32[\text{Yb}] + 0.32[\text{Lu}] + 1.24[\text{Sc}] - 2.33[\text{O}] - 3.99[\text{N}] - 1.74[\text{S}] \geq 0.0003 \quad \cdots \text{formula 1}$$

where [Pr], [Sm], [Eu], [Gd], [Tb], [Dy], [Ho], [Er], [Tm], [Yb], [Lu], [Sc], [O], [N], and [S] are the contents [mass%] of the elements, and if the elements are not included, the contents are 0.

(2) The steel material according to (1), wherein the chemical composition further includes, by mass%, one or more of

Nb: 0.003 to 3.000%,
 Ti: 0.005 to 0.500%,
 Ta: 0.001 to 0.500%,
 V: 0.001 to 1.00%,
 Cu: 0.001 to 3.00%,
 Ni: 0.001 to 60.00%,
 Cr: 0.001 to 30.00%,
 Mo: 0.001 to 5.00%,
 W: 0.001 to 2.00%,
 B: 0.0001 to 0.0200%,
 Co: 0.001 to 3.00%,
 Be: 0.0003 to 0.050%,

Ag: 0.001 to 0.500%,
 Zr: 0.0001 to 0.5000%,
 Hf: 0.0001 to 0.5000%,
 Ca: 0.0001 to 0.0500%,
 5 Mg: 0.0001 to 0.0500%,
 at least one of La, Ce, Nd, Pm, and Y: 0.0001 to 0.5000% in total,
 Sn: 0.001 to 0.300%,
 Sb: 0.001 to 0.300%,
 10 Te: 0.001 to 0.100%,
 Se: 0.001 to 0.100%,
 As: 0.001 to 0.050%,
 Bi: 0.001 to 0.500%, and
 Pb: 0.001 to 0.500%.

15 [ADVANTAGEOUS EFFECTS OF INVENTION]

[0009] According to the present invention, it is possible to provide a steel material having an improved effect of inhibition of recrystallization or improved in inhibition of recrystallization.

20 BRIEF DESCRIPTION OF DRAWINGS

[0010]

FIG. 1 is a graph showing test conditions of a compression test in the examples.

25 FIG. 2 is a graph showing a method of determination of a softening ratio extracted from Naoki Maruyama et al., "Form of Nb at an Early Stage of Recovery and Recrystallization in Austenite of Hot-Deformed Steel", J. Japan Inst. Metals, Vol. 60, No. 11 (1996), pp. 1051 to 1057.

DESCRIPTION OF EMBODIMENTS

30 <Steel Material>

[0011] The steel material according to an embodiment of the present invention has a chemical composition consisting of, by mass%,

35 C: 0.001 to 1.000%,
 Si: 0.01 to 3.00%,
 Mn: 0.10 to 4.50%,
 P: 0.300% or less,
 40 S: 0.0300% or less,
 Al: 0.001 to 5.000%,
 N: 0.2000% or less,
 O: 0.0100% or less,
 at least one X element selected from the group consisting of Pr: 0 to 0.8000%, Sm: 0 to 0.8000%, Eu: 0 to 0.8000%,
 45 Gd: 0 to 0.8000%, Tb: 0 to 0.8000%, Dy: 0 to 0.8000%, Ho: 0 to 0.8000%, Er: 0 to 0.8000%, Tm: 0 to 0.8000%, Yb:
 0 to 0.8000%, Lu: 0 to 0.8000%, and Sc: 0 to 0.8000%,
 Nb: 0 to 3.000%,
 Ti: 0 to 0.500%,
 Ta: 0 to 0.500%,
 50 V: 0 to 1.00%,
 Cu: 0 to 3.00%,
 Ni: 0 to 60.00%,
 Cr: 0 to 30.00%,
 Mo: 0 to 5.00%,
 55 W: 0 to 2.00%,
 B: 0 to 0.0200%,
 Co: 0 to 3.00%,
 Be: 0 to 0.050%,

Ag: 0 to 0.500%,
 Zr: 0 to 0.5000%,
 Hf: 0 to 0.5000%,
 Ca: 0 to 0.0500%,
 Mg: 0 to 0.0500%,
 at least one of La, Ce, Nd, Pm, and Y: 0 to 0.5000% in total,
 Sn: 0 to 0.300%,
 Sb: 0 to 0.300%,
 Te: 0 to 0.100%,
 Se: 0 to 0.100%,
 As: 0 to 0.050%,
 Bi: 0 to 0.500%,
 Pb: 0 to 0.500%, and
 balance: Fe and impurities, and
 satisfying the following formula 1:

$$0.40[\text{Pr}] + 0.37[\text{Sm}] + 0.37[\text{Eu}] + 0.36[\text{Gd}] + 0.35[\text{Tb}] + 0.34[\text{Dy}] + 0.34[\text{Ho}] + 0.33[\text{Er}] + 0.33[\text{Tm}] + 0.32[\text{Yb}] + 0.32[\text{Lu}] + 1.24[\text{Sc}] - 2.33[\text{O}] - 3.99[\text{N}] - 1.74[\text{S}] \geq 0.0003 \quad \cdots \text{ formula 1}$$

where [Pr], [Sm], [Eu], [Gd], [Tb], [Dy], [Ho], [Er], [Tm], [Yb], [Lu], [Sc], [O], [N], and [S] are the contents [mass%] of the elements, and if the elements are not included, the contents are 0.

[0012] To inhibit recrystallization of austenite grains, as stated above, it is necessary to end the finish rolling at a low temperature. However, in this case, sometimes a need arises to wait to start finish rolling until the steel material falls to a suitable temperature. Therefore, a drop in productivity is liable to be invited. In particular, if the product is a relatively thick steel material such as used in building materials and other applications, for example, sometimes considerable time is required for causing a sufficient drop in temperature at the center part of the steel material before finish rolling. In such a case, the drop in productivity becomes particularly remarkable. For this reason, to produce a steel material without impairing productivity, causing the hot rolling to end at a higher temperature is generally desirable, but on the other hand, inhibition of recrystallization is sought to refine the metallic structure.

[0013] Therefore, to refine the metallic structure while improving the productivity, it is necessary to expand the non-recrystallization temperature region. Specifically, it is necessary to make the temperature at which recrystallization of austenite grains starts rise. Explaining this in more detail, if hot rolling a steel material, the crystals in the steel are crushed by the hot rolling, the arrangement of Fe atoms which were aligned in good order in the crystals is disturbed, a large number of disconnected structures called "deformed bands" are formed, and a large number of step shaped relief shapes (ledges) are formed at the crystal grain boundaries. However, at this time, if the rolling temperature is high, the Fe atoms act on their own so as to eliminate the deformed bands or ledges and to return the Fe atoms from a disturbed unstable state to stable crystals where the Fe atoms are cleanly arranged. This phenomenon is called "recrystallization". On the other hand, if the rolling temperature is low (for example, if less than about 800°C), the Fe atoms cannot move, therefore the hot rolling ends with ledges and deformed bands remaining at many locations at the grain boundaries or in the grains.

[0014] In the process of cooling after the end of hot rolling, the metallic structure transforms from austenite to ferrite, but such transformation generally occurs from the locations where the arrangement of Fe atoms in the austenite is disturbed. Therefore, if austenite recrystallizes during the hot rolling, the locations where the arrangement of Fe atoms is disturbed become only the grain boundaries, therefore new crystals of ferrite can only be formed from the grain boundaries of the austenite. On the other hand, for example, if hot rolling at a low temperature of less than about 800°C, it becomes possible to form large numbers of new crystals of ferrite from the ledges or deformed bands present at many locations of the austenite. A steel material with a metallic structure of austenite and a steel material with a metallic structure of martensite does not transform to ferrite, but due to the inhibition of recrystallization, the strain accumulated at the austenite grains in the hot rolling process increases and the grains are refined. In this way, hot rolling at a low temperature, more specifically finish rolling at a low temperature is extremely effective for refining the metallic structure, but as explained above, from the viewpoint of productivity, ending the hot rolling at a high temperature is being sought. Therefore, to refine the metallic structure while improving productivity, it is preferable to raise the recrystallization start temperature.

[0015] Therefore, the inventors studied the elements enabling inhibition or retardation of recrystallization of austenite grains. As a result, the inventors discovered that by making the amount of specific elements dissolved in the steel, i.e., the elements of Pr, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Sc (below, also referred to as the "X elements") within

a predetermined range (i.e., by making the effective amount of X elements corresponding to the left side of formula 1 0.0003% or more) while considering the relationship with the inclusions these elements form in the steel, more specifically the oxides, nitrides, and sulfides of these elements, it is possible to inhibit or retard the recrystallization of austenite grains and make the recrystallization start temperature shift to the high temperature side due to the inhibition or retardation of the recrystallization. Therefore, according to the present invention, even if hot rolling at a comparatively high temperature, in particular finish rolling, it is possible to obtain a steel material in which recrystallization is remarkably inhibited, therefore it is possible to improve the productivity and refine the metallic structure in the steel material which is finally obtained. As a result, it becomes possible to improve the properties relating to the refinement of the metallic structure, for example, improve the toughness, and realize reduction of the production costs of the steel material, shortening of the production process, etc.

[0016] While not intended to be constrained to any specific theory, it is believed that the X elements according to an embodiment of the present invention are affixed to dislocations and other lattice defects introduced into the steel at the time of hot rolling and, for example, the dislocations are blocked from becoming rearranged and moving to stable arrangements whereby recrystallization is inhibited. The above X elements are all larger in atomic radius compared with the Nb which has been used in the prior art, therefore it is believed that by making such elements having relatively large atomic radii be affixed at dislocations and other lattice defects, the effect of blocking rearrangement of dislocations, etc., becomes higher and as a result it is possible to achieve an effect of inhibition of recrystallization at least equal to or higher than a conventional steel material using Nb. Therefore, in the present invention, it can be said to be extremely important to make a large number of such elements having relatively large atomic radii dissolve in the steel.

[0017] However, there is the problem in that these X elements easily bond with the O (oxygen), N (nitrogen), and S (sulfur) present in the steel to form inclusions comprised of oxides, nitrides, and sulfides. If the X elements form such inclusions in the steel, the amount of dissolved X elements able to contribute to inhibition of recrystallization becomes smaller and the effect of inhibition of recrystallization obtained by the X elements becoming affixed to dislocations and other lattice defects can no longer be sufficiently obtained. In the present invention, the amount of dissolved X elements considering such inclusions can be calculated as the effective amount of X elements by the formula 1 explained in detail later and the effective amount can be controlled within a predetermined range, i.e., 0.0003% or more, so as to achieve a higher effect of inhibition of recrystallization.

[0018] The X elements in the present invention, as explained above, easily bond with O, N, and S to form inclusions. Therefore, it is generally difficult to secure predetermined dissolved amounts in the steel. Due to such a situation, the effect of inhibition of recrystallization due to the X elements was not conventionally known. However, due to the advances in refining technology in recent years, it has become possible to reduce the contents of O, N, S, and other elements generally present in the steel as impurities to extremely low levels. Due in part to this, it was possible to dissolve the X elements in a predetermined range. Therefore, the effect of inhibition of recrystallization due to the dissolved X elements was clarified for the first time by the inventors and is extremely unexpected and further should be said to be surprising.

[0019] Below, the steel material according to an embodiment of the present invention will be explained in more detail. In the following explanation, the units "%" of contents of the elements mean "mass%" unless otherwise indicated. Further, in this Description, the "to" showing ranges of numerical values is used in the sense including the numerical values described before and after it as the lower limit value and upper limit value unless otherwise indicated.

[C: 0.001 to 1.000%]

[0020] Carbon (C) is an element required for stabilization of hardness and/or securing strength. To sufficiently obtain these effects, the C content is 0.001% or more. The C content may also be 0.005% or more, 0.010% or more, or 0.020% or more. On the other hand, if excessively including C, the toughness, bendability, and/or weldability sometimes fall. Therefore, the C content is 1.000% or less. The C content may also be 0.800% or less, 0.600% or less, or 0.500% or less.

[Si: 0.01 to 3.00%]

[0021] Silicon (Si) is a deoxidizing element and an element also contributing to improvement of strength. To sufficiently obtain these effects, the Si content is 0.01% or more. The Si content may also be 0.05% or more, 0.10% or more, or 0.30% or more. On the other hand, if excessively containing Si, sometimes the toughness falls or defects in surface quality called "scale defects" occur. Therefore, the Si content is 3.00% or less. The Si content may also be 2.00% or less, 1.00% or less, or 0.60% or less.

[Mn: 0.10 to 4.50%]

[0022] Manganese (Mn) is an element effective for improvement of the hardenability and/or strength and also an effective austenite stabilizing element. To sufficiently obtain these effects, the Mn content is 0.10% or more. The Mn

content may also be 0.50% or more, 0.70% or more, or 1.00% or more. On the other hand, if excessively containing Mn, sometimes MnS harmful to toughness is formed and the oxidation resistance is made to fall. Therefore, the Mn content is 4.50% or less. The Mn content may also be 4.00% or less, 3.50% or less, or 3.00% or less.

[P: 0.300% or Less]

[0023] Phosphorus (P) is an element mixed in during the production process. The P content may also be 0%. However, to reduce the P content to less than 0.0001%, time is required for refining and a drop in the productivity is invited. Therefore, the P content may also be 0.0001% or more, 0.0005% or more, 0.001% or more, 0.003% or more, or 0.005% or more. The P content may also be 0.007% or more from the viewpoint of the production costs. On the other hand, if excessively containing P, the workability and/or toughness of the steel material sometimes fall. Therefore, the P content is 0.300% or less. The P content may also be 0.100% or less, 0.030% or less, or 0.010% or less.

[S: 0.0300% or Less]

[0024] Sulfur (S) is an element mixed in during the production process. From the viewpoint of reducing inclusions formed with the X elements according to an embodiment of the present invention, the smaller the amount the more preferable. Accordingly, the S content may also be 0%. However, to reduce the S content to less than 0.0001%, time is required for refining and a drop in the productivity is invited. Therefore, the S content may also be 0.0001% or more, 0.0005% or more, or 0.0010% or more. On the other hand, if excessively containing S, the effective amount of the X element falls and the toughness sometimes fall. Therefore, the S content is 0.0300% or less. The S content is preferably 0.0100% or less, more preferably 0.0050% or less, most preferably 0.0030% or less.

[Al: 0.001 to 5.000%]

[0025] Aluminum (Al) is a deoxidizing element and is an element effective for improving the corrosion resistance and/or heat resistance. To obtain these effects, the Al content is 0.001% or more. The Al content may also be 0.010% or more, 0.100% or more, or 0.200% or more. In particular, from the viewpoint of sufficiently improving the heat resistance, the Al content may also be 1.000% or more, 2.000% or more, or 3.000% or more. On the other hand, if excessively containing Al, coarse inclusions are formed and the toughness is made to fall and sometimes fracture or other trouble occurs in the production process and/or the fatigue resistance characteristic is made to fall. Therefore, the Al content is 5.000% or less. The Al content may also be 4.500% or less, 4.000% or less, or 3.500% or less. In particular, from the viewpoint of inhibiting the drop in toughness, the Al content may also be 1.500% or less, 1.000% or less, or 0.300% or less.

[N: 0.2000% or Less]

[0026] Nitrogen (N) is an element mixed in during the production process. From the viewpoint of reducing the inclusions formed with the X elements according to an embodiment of the present invention, the smaller the amount the better. Accordingly, the N content may also be 0%. However, to reduce the N content to less than 0.0001%, time is required for refining and a drop in the productivity is invited. Therefore, the N content may also be 0.0001% or more, 0.0005% or more, or 0.0010% or more. On the other hand, N is also an element effective for stabilization of austenite and may be intentionally included in accordance with need. In this case, the N content is preferably 0.0100% or more and may also be 0.0200% or more or 0.0500% or more. However, if excessively containing N, sometimes the effective amount of the X elements falls and the toughness falls. Therefore, the N content is 0.2000% or less. The N content may also be 0.1500% or less, 0.1000% or less, or 0.0800% or less.

[O: 0.0100% or Less]

[0027] Oxygen (O) is an element mixed in during the production process. From the viewpoint of reducing the inclusions formed with the X elements according to an embodiment of the present invention, the smaller the amount the better. Accordingly, the O content may also be 0%. However, to reduce the O content to less than 0.0001%, time is required for refining and a drop in the productivity is invited. Therefore, the O content may also be 0.0001% or more, 0.0005% or more, or 0.0010% or more. On the other hand, if excessively containing O, coarse inclusions are formed, the effective amount of X elements falls, and the formability and/or toughness of the steel material sometimes falls. Therefore, the O content is 0.0100% or less. The O content may also be 0.0080% or less, 0.0060% or less, or 0.0040% or less.

[At Least One X Element Selected From Group Consisting Of Pr: 0 to 0.8000%, Sm: 0 to 0.8000%, Eu: 0 to 0.8000%, Gd: 0 to 0.8000%, Tb: 0 to 0.8000%, Dy: 0 to 0.8000%, Ho: 0 to 0.8000%, Er: 0 to 0.8000%, Tm: 0 to 0.8000%, Yb: 0 to 0.8000%, Lu: 0 to 0.8000%, and Sc: 0 to 0.8000%]

[0028] The X elements according to an embodiment of the present invention are Pr: 0 to 0.8000%, Sm: 0 to 0.8000%, Eu: 0 to 0.8000%, Gd: 0 to 0.8000%, Tb: 0 to 0.8000%, Dy: 0 to 0.8000%, Ho: 0 to 0.8000%, Er: 0 to 0.8000%, Tm: 0 to 0.8000%, Yb: 0 to 0.8000%, Lu: 0 to 0.8000%, and Sc: 0 to 0.8000%. By praseodymium (Pr), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), and scandium (Sc) being present in a dissolved state in the austenite, the effect of inhibition of recrystallization can be exhibited. By exhibiting the effect of inhibition of recrystallization, even if hot rolling, in particular finish rolling at a relatively high temperature, it is possible to refine the metallic structure in the steel material finally obtained, therefore for example, it becomes possible to improve the toughness evaluated by the Charpy impact property, etc., and greatly improve the productivity.

[0029] The X elements may all be used as single elements alone or may be used as all sorts of specific combinations of two types or more of these elements. Further, the X elements need only be present in amounts satisfying formula 1 explained in detail later. Lower limit values of the same are not particularly prescribed. However, for example, the content or total contents of the X elements may also be 0.0010% or more, preferably 0.0050% or more, more preferably 0.0150% or more and still more preferably 0.0300% or more, most preferably 0.0500% or more. On the other hand, even if excessively containing X elements, the effect becomes saturated. For this reason, including the X elements in the steel material more than necessary is liable to invite a rise in the production costs. Therefore, the contents of the X elements are 0.8000% or less and may be, for example, 0.7000% or less, 0.6000% or less, 0.5000% or less, 0.4000% or less, or 0.3000% or less. Further, the total of the contents of the X elements is 9.6000% or less and may be, for example, 6.0000% or less, 5.0000% or less, 4.0000% or less, 2.0000% or less, 1.0000% or less, or 0.5000% or less.

[0030] The basic chemical composition of the steel material according to an embodiment of the present invention is as explained above. Further, the steel material may, according to need, contain one or more of the following optional elements. For example, the steel material may also contain one or more of Nb: 0 to 3.000%, Ti: 0 to 0.500%, Ta: 0 to 0.500%, V: 0 to 1.00%, Cu: 0 to 3.00%, Ni: 0 to 60.00%, Cr: 0 to 30.00%, Mo: 0 to 5.00%, W: 0 to 2.00%, B: 0 to 0.0200%, Co: 0 to 3.00%, Be: 0 to 0.050%, and Ag: 0 to 0.500%. Further, the steel material may also contain one or more of Zr: 0 to 0.5000%, Hf: 0 to 0.5000%, Ca: 0 to 0.0500%, Mg: 0 to 0.0500%, and at least one of La, Ce, Nd, Pm, and Y: 0 to 0.5000% in total. Further, the steel material may contain one or both of Sn: 0 to 0.300% and Sb: 0 to 0.300%. Further, the steel material may contain one or more of Te: 0 to 0.100%, Se: 0 to 0.100%, As: 0 to 0.050%, Bi: 0 to 0.500%, and Pb: 0 to 0.500%. Below, these optional elements will be explained in detail.

[Nb: 0 to 3.000%]

[0031] Niobium (Nb) is an element contributing to precipitation strengthening and inhibition of recrystallization, etc. The Nb content may also be 0%, but to obtain these effects, the Nb content is preferably 0.003% or more. For example, the Nb content may also be 0.005% or more or 0.010% or more. In particular, from the viewpoint of sufficiently obtaining precipitation strengthening, the Nb content may also be 1.000% or more or 1.500% or more. On the other hand, if excessively containing Nb, the effect becomes saturated and sometimes the workability and/or toughness is made to fall. Therefore, the Nb content is 3.000% or less. The Nb content may also be 2.800% or less, 2.500% or less, or 2.000% or less. In particular, from the viewpoint of inhibiting a drop in toughness of the heat affected zone (HAZ), the Nb content is preferably 0.100% or less and may also be 0.080% or less, 0.050% or less, or 0.030% or less.

[Ti: 0 to 0.500%]

[0032] Titanium (Ti) is an element contributing to improvement of the strength of the steel material due to precipitation strengthening, etc. The Ti content may also be 0%, but to obtain such an effect, the Ti content is preferably 0.005% or more. The Ti content may also be 0.010% or more, 0.050% or more, or 0.080% or more. On the other hand, if excessively containing Ti, a large amount of precipitates are formed and sometimes the toughness is lowered. Therefore, the Ti content is 0.500% or less. The Ti content may also be 0.300% or less, 0.200% or less, or 0.100% or less.

[Ta: 0 to 0.500%]

[0033] Tantalum (Ta) is an element effective for controlling the form of the carbides and the increase of the strength. The Ta content may also be 0%, but to obtain these effects, the Ta content is preferably 0.001% or more. The Ta content may also be 0.005% or more, 0.010% or more, or 0.050% or more. On the other hand, if excessively containing Ta, a large number of fine Ta carbides precipitate, an excessive rise in strength of the steel material is invited, and as a result

sometimes a drop in ductility and a drop in cold workability are caused. Therefore, the Ta content is 0.500% or less. The Ta content may also be 0.300% or less, 0.100% or less, or 0.080% or less.

[V: 0 to 1.00%]

[0034] Vanadium (V) is an element contributing to improvement of the strength of the steel material due to precipitation strengthening, etc. The V content may also be 0%, but to obtain such an effect, the V content is preferably 0.001% or more. The V content may also be 0.01% or more, 0.02% or more, 0.05% or more, or 0.10% or more. On the other hand, if excessively containing V, a large amount of precipitates are formed and sometimes the toughness is made to drop. Therefore, the V content is 1.00% or less. The V content may also be 0.80% or less, 0.60% or less, or 0.50% or less.

[Cu: 0 to 3.00%]

[0035] Copper (Cu) is an element contributing to improvement of the strength and/or corrosion resistance. The Cu content may also be 0%, but to obtain these effects, the Cu content is preferably 0.001% or more. The Cu content may also be 0.01% or more, 0.10% or more, 0.15% or more, 0.20% or more, or 0.30% or more. On the other hand, if excessively containing Cu, deterioration of the toughness and weldability is sometimes invited. Therefore, the Cu content is 3.00% or less. The Cu content may also be 2.00% or less, 1.50% or less, 1.00% or less, or 0.50% or less.

[Ni: 0 to 60.00%]

[0036] Nickel (Ni) is an element contributing to improvement of the strength and/or heat resistance and an effective austenite stabilizing element. The Ni content may also be 0%, but to obtain these effects, the Ni content is preferably 0.001% or more. The Ni content may also be 0.01% or more, 0.10% or more, 0.50% or more, 0.70% or more, 1.00% or more, or 3.00% or more. In particular, from the viewpoint of sufficiently improving the heat resistance, the Ni content may also be 30.00% or more, 35.00% or more, or 40.00% or more. On the other hand, if excessively containing Ni, in addition to the increase of the alloy cost, sometimes the deformation resistance at the time of hot working increases and the load on the facilities becomes larger. Therefore, the Ni content is 60.00% or less. The Ni content may also be 55.00% or less or 50.00% or less. In particular, from the viewpoint of economy and/or the viewpoint of inhibition of the drop of weldability, the Ni content may also be 15.00% or less, 10.00% or less, 6.00% or less, or 4.00% or less.

[Cr: 0 to 30.00%]

[0037] Chromium (Cr) is an element contributing to improvement of the strength and/or corrosion resistance. The Cr content may also be 0%, but to obtain these effects, the Cr content is preferably 0.001% or more. The Cr content may also be 0.01% or more, 0.05% or more, 0.10% or more, or 0.50% or more. In particular, from the viewpoint of sufficiently improving the corrosion resistance, the Cr content may also be 10.00% or more, 12.00% or more, or 15.00% or more. On the other hand, if excessively containing Cr, in addition to the alloy cost, the toughness sometimes fall. Therefore, the Cr content is 30.00% or less. The Cr content may also be 28.00% or less, 25.00% or less, or 20.00% or less. In particular, from the viewpoint of inhibiting a drop in the weldability and/or workability, the Cr content may also be 10.00% or less, 9.00% or less, or 7.50% or less.

[Mo: 0 to 5.00%]

[0038] Molybdenum (Mo) is an element raising the hardenability of steel and contributing to improvement of the strength and is an element also contributing to improvement of the corrosion resistance. The Mo content may also be 0%, but to obtain these effects, the Mo content is preferably 0.001% or more. The Mo content may also be 0.01% or more, 0.02% or more, 0.50% or more, or 1.00% or more. On the other hand, if excessively containing Mo, sometimes the deformation resistance at the time of hot working increases and the load on the facilities becomes greater. Therefore, the Mo content is 5.00% or less. The Mo content may also be 4.50% or less, 4.00% or less, 3.00 or less, or 1.50% or less.

[W: 0 to 2.00%]

[0039] Tungsten (W) is an element raising the hardenability of steel and contributing to improvement of the strength. The W content may also be 0%, but to obtain such effects, the W content is preferably 0.001% or more. The W content may also be 0.01% or more, 0.02% or more, 0.05% or more, 0.10% or more, or 0.50% or more. On the other hand, if excessively containing W, the ductility or the weldability sometimes fall. Therefore, the W content is 2.00% or less. The W content may also be 1.80% or less, 1.50% or less, or 1.00% or less.

[B: 0 to 0.0200%]

[0040] Boron (B) is an element contributing to improvement of the strength. The B content may also be 0%, but to obtain such an effect, the B content is preferably 0.0001% or more. The B content may also be 0.0003% or more, 0.0005% or more, or 0.0007% or more. On the other hand, if excessively containing B, the toughness and/or weldability sometimes fall. Therefore, the B content is 0.0200% or less. The B content may also be 0.0100% or less, 0.0050% or less, 0.0030% or less, or 0.0020% or less.

[Co: 0 to 3.00%]

[0041] Cobalt (Co) is an element contributing to improvement of the hardenability and/or heat resistance. The Co content may also be 0%, but to obtain these effects, the Co content is preferably 0.001% or more. The Co content may also be 0.01% or more, 0.02% or more, 0.05% or more, 0.10% or more, or 0.50% or more. On the other hand, if excessively containing Co, the hot workability sometimes falls. This leads to an increase in the material costs as well. Therefore, the Co content is 3.00% or less. The Co content may also be 2.50% or less, 2.00% or less, 1.50% or less, or 0.80% or less.

[Be: 0 to 0.050%]

[0042] Beryllium (Be) is an element effective for raising the strength and refining the structure of the base material. The Be content may also be 0%, but to obtain such an effect, the Be content is preferably 0.0003% or more. The Be content may also be 0.0005% or more, 0.001% or more, or 0.010% or more. On the other hand, if excessively containing Be, the formability sometimes fall. Therefore, the Be content is 0.050% or less. The Be content may also be 0.040% or less, 0.030% or less, or 0.020% or less.

[Ag: 0 to 0.500%]

[0043] Silver (Ag) is an element effective for raising the strength and refining the structure of the base material. The Ag content may also be 0%, but to obtain such effects, the Ag content is preferably 0.001% or more. The Ag content may also be 0.010% or more, 0.020% or more, 0.030% or more, or 0.050% or more. On the other hand, if excessively containing Ag, the formability sometimes falls. Therefore, the Ag content is 0.500% or less. The Ag content may also be 0.400% or less, 0.300% or less, or 0.200% or less.

[Zr: 0 to 0.5000%]

[0044] Zirconium (Zr) is an element able to control the form of sulfides. The Zr content may also be 0%, but to obtain such an effect, the Zr content is preferably 0.0001% or more. On the other hand, even if excessively including Zr, the effect becomes saturated and therefore inclusion of Zr in the steel material more than necessary is liable to invite a rise in the production costs. Therefore, the Zr content is 0.5000% or less.

[Hf: 0 to 0.5000%]

[0045] Hafnium (Hf) is an element able to control the form of sulfides. The Hf content may also be 0%, but to obtain such an effect, the Hf content is preferably 0.0001% or more. On the other hand, even if excessively containing Hf, the effect becomes saturated and therefore inclusion of Hf in the steel material more than necessary is liable to invite a rise in the production costs. Therefore, the Hf content is 0.5000% or less.

[Ca: 0 to 0.0500%]

[0046] Calcium (Ca) is an element able to control the form of sulfides. The Ca content may also be 0%, but to obtain such an effect, the Ca content is preferably 0.0001% or more. On the other hand, even if excessively containing Ca, the effect becomes saturated and therefore inclusion of Ca in the steel material more than necessary is liable to invite a rise in the production costs. Therefore, the Ca content is 0.5000% or less.

[Mg: 0 to 0.0500%]

[0047] Magnesium (Mg) is an element able to control the form of sulfides. The Mg content may also be 0%, but to obtain such an effect, the Mg content is preferably 0.0001% or more. The Mg content may also be more than 0.0015%,

0.0016% or more, 0.0018% or more, or 0.0020% or more. On the other hand, even if excessively containing Mg, the effect becomes saturated and sometimes the cold workability and/or toughness fall due to the formation of the coarse inclusions. Therefore, the Mg content is 0.0500% or less. The Mg content may also be 0.0400% or less, 0.0300% or less, or 0.0200% or less.

[At Least One of La, Ce, Nd, Pm, and Y: 0 to 0.5000% in Total]

[0048] Lanthanum (La), cerium (Ce), neodymium (Nd), promethium (Pm), and yttrium (Y) are elements able to control the form of sulfides in the same way as Ca and Mg. The total of content of at least one of La, Ce, Nd, Pm, and Y may also be 0%, but to obtain such an effect, 0.0001% or more is preferable. The total of the content of at least one of La, Ce, Nd, Pm, and Y may be 0.0002% or more, 0.0003% or more, or 0.0004% or more. On the other hand, even if excessively containing, the effect becomes saturated and sometimes coarse oxides, etc., are formed and the cold workability sometimes fall. Therefore, the total of the content of at least one of La, Ce, Nd, Pm, and Y is 0.5000% or less and may also be 0.4000% or less, 0.3000% or less, or 0.2000% or less.

[Sn: 0 to 0.300%]

[0049] Tin (Sn) is an element effective for improvement of the corrosion resistance. The Sn content may also be 0%, but to obtain such an effect, the Sn content is preferably 0.001% or more. The Sn content may also be 0.010% or more, 0.020% or more, 0.030% or more, or 0.050% or more. On the other hand, if excessively containing Sn, a drop in the toughness, in particular the low temperature toughness, is sometimes invited. Therefore, the Sn content is 0.300% or less. The Sn content may also be 0.250% or less, 0.200% or less, or 0.150% or less.

[Sb: 0 to 0.300%]

[0050] Antimony (Sb), in the same way as Sn, is an element effective for improvement of the corrosion resistance. In particular, the effect can be made to increase by making it be included combined with Sn. The Sb content may also be 0%, but to obtain the effect of improvement of the corrosion resistance, the Sb content is preferably 0.001% or more. The Sb content may also be 0.010% or more, 0.020% or more, 0.030% or more, or 0.050% or more. On the other hand, if excessively containing Sb, a drop in the toughness, in particular the low temperature toughness, is sometimes invited. Therefore, the Sb content is 0.300% or less. The Sb content may also be 0.250% or less, 0.200% or less, or 0.150% or less.

[Te: 0 to 0.100%]

[0051] Tellurium (Te) is an element effective for improving the machineability of steel since it forms low melting point compounds with Mn, S, etc., to raise the lubrication effect. The Te content may also be 0%, but to obtain such an effect, the Te content is preferably 0.001% or more. The Te content may also be 0.010% or more, 0.020% or more, 0.030% or more, or 0.040% or more. On the other hand, even if excessively containing Te, the effect becomes saturated and an increase in the alloy cost is invited. Therefore, the Te content is 0.100% or less. The Te content may also be 0.090% or less, 0.080% or less, or 0.070% or less.

[Se: 0 to 0.100%]

[0052] Selenium (Se) is an element effective for improving the machineability of steel since selenium compounds formed in steel cause a change in the shear plastic deformation of a machined material and result in cutting scraps easily being pulverized. The Se content may also be 0%, but to obtain such an effect, the Se content is preferably 0.001% or more. The Se content may also be 0.010% or more, 0.020% or more, 0.030% or more, or 0.040% or more. On the other hand, even if excessively containing Se, the effect becomes saturated and an increase in the alloy cost is invited. Therefore, the Se content is 0.100% or less. The Se content may also be 0.090% or less, 0.080% or less, or 0.070% or less.

[As: 0 to 0.050%]

[0053] Arsenic (As) is an element effective for improving the machineability of steel. The As content may also be 0%, but to obtain such an effect, the As content is preferably 0.001% or more. The As content may also be 0.005% or more or 0.010% or more. On the other hand, if excessively containing As, the hot workability sometimes falls. Therefore, the As content is 0.050% or less. The As content may also be 0.040% or less, 0.030% or less, or 0.020% or less.

[Bi: 0 to 0.500%]

[0054] Bismuth (Bi) is an element effective for improving the machineability of steel. The Bi content may also be 0%, but to obtain such an effect, the Bi content is preferably 0.001% or more. The Bi content may also be 0.010% or more, 0.020% or more, 0.030% or more, or 0.050% or more. On the other hand, even if excessively containing Bi, the effect becomes saturated and an increase in the alloy cost is invited. Therefore, the Bi content is 0.500% or less. The Bi content may also be 0.400% or less, 0.300% or less, or 0.200% or less.

[Pb: 0 to 0.500%]

[0055] Lead (Pb) is an element effective for improving the machineability of steel since it melts and promotes the progression of cracks due to the rise in temperature due to machining. The Pb content may also be 0%, but to obtain such an effect, the Pb content is preferably 0.001% or more. The Pb content may also be 0.010% or more, 0.020% or more, 0.030% or more, or 0.050% or more. On the other hand, if excessively containing Pb, the hot workability sometimes fall. Therefore, the Pb content is 0.500% or less. The Pb content may also be 0.400% or less, 0.300% or less, or 0.200% or less.

[0056] In the steel material according to an embodiment of the present invention, the balance other than the above elements consists of Fe and impurities. The "impurities" are constituents, etc., entering due to various factors in the production process such as the ore, scrap, and other such raw materials when industrially producing the steel material.

[Effective Amount of X Elements]

[0057] According to an embodiment of the present invention, the effective amount of the X elements consisting of Pr, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Sc is found by the left side of the following formula 1. The value satisfies the formula 1.

$$0.40[\text{Pr}] + 0.37[\text{Sm}] + 0.37[\text{Eu}] + 0.36[\text{Gd}] + 0.35[\text{Tb}] + 0.34[\text{Dy}] + 0.34[\text{Ho}] + 0.33[\text{Er}] + 0.33[\text{Tm}] + 0.32[\text{Yb}] + 0.32[\text{Lu}] + 1.24[\text{Sc}] - 2.33[\text{O}] - 3.99[\text{N}] - 1.74[\text{S}] \geq 0.0003 \quad \cdots \text{formula 1}$$

where [Pr], [Sm], [Eu], [Gd], [Tb], [Dy], [Ho], [Er], [Tm], [Yb], [Lu], [Sc], [O], [N], and [S] are the contents [mass%] of the elements, and if the elements are not included, the contents are 0.

[0058] By making the effective amount of the X elements satisfy the above formula 1, it is possible to increase the amounts of these elements present in a dissolved state in the steel, therefore it is possible to inhibit or retard the recrystallization of austenite grains and possible to make the recrystallization start temperature shift to the high temperature side due to such inhibition or retardation of recrystallization. Explained in more detail, these X elements (below, sometimes simply referred to as "X") tend to bond with the O (oxygen), N (nitrogen), and S (sulfur) present in the steel to form inclusions consisting of oxides (X_2O_3), nitrides (XN), and sulfides (XS). If forming the inclusions, at least the X elements in these inclusions cannot contribute to inhibition of recrystallization of austenite grains. Therefore, to inhibit the recrystallization of austenite grains, it is necessary to increase the amount of X elements not forming inclusions and present in the steel in the dissolved state (i.e., the dissolved amount of X elements in the steel).

[0059] Here, the dissolved amount of the X elements in the steel can be roughly calculated by subtracting from the amount of X elements contained in the steel the maximum amount able to be consumed for forming inclusions (oxides, nitrides, and sulfides). Therefore, in this embodiment of the present invention, the dissolved amount of X elements roughly calculated in this way is the amount of X elements effective for inhibiting recrystallization of austenite grains (i.e., the "effective amount of X elements"). Specifically, it is defined by the following formula A:

$$\text{Effective amount of X elements [atoms \%]} = \sum (M_{[\text{Fe}]} / M_{[\text{X}]}) \times [\text{X}] - (M_{[\text{Fe}]} / M_{[\text{O}]}) \times [\text{O}] \times 2/3 - (M_{[\text{Fe}]} / M_{[\text{N}]}) \times [\text{N}] - (M_{[\text{Fe}]} / M_{[\text{S}]}) \times [\text{S}] \quad \cdots \text{formula A}$$

where X indicates the X elements of Pr, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Sc, $M_{[\text{X}]}$ indicates the amount of atoms of the X elements, $M_{[\text{Fe}]}$ indicates the amount of atoms of Fe, $M_{[\text{O}]}$ indicates the amount of atoms of O, $M_{[\text{N}]}$ indicates the amount of atoms of N, $M_{[\text{S}]}$ indicates the amount of atoms of S, [X], [O], [N], and [S] are the contents [mass%] of elements corresponding to the same, if the elements are not included, the contents are 0.

[0060] Explaining the above formula A in detail below, first, the steel material according to an embodiment of the present invention contains various alloy elements, but it is clear that the steel material as a whole is substantially

comprised of Fe or, if the optional elements Ni and/or Cr are included in relatively large amounts (the respective maximum contents being 60.00% and 30.00%), it is substantially comprised of Ni and/or Cr in addition to Fe. On the other hand, it is well known that the amounts of atoms of Ni and Cr are equal to the amounts of atoms of Fe. For this reason, even if the steel material includes relatively large amounts of Ni and/or Cr, the atom% of the X elements of Pr, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Sc can be calculated approximately by multiplying the contents of the X elements [mass %] with the ratio of the amount of atoms of Fe and the amounts of atoms of the X elements, i.e., $(M_{[Fe]}/M_{[X]}) \times [X]$. Therefore, by totaling the amounts of X elements calculated by $(M_{[Fe]}/M_{[X]}) \times [X]$ (i.e., by calculating $\sum (M_{[Fe]}/M_{[X]}) \times [X]$), it is possible to calculate the atom% of the X elements as a whole.

[0061] Next, by subtracting the maximum amount (atom%) able to be consumed for forming oxides ($X_2 O_3$), nitrides (XN), and sulfides (XS) among the atom% of the X elements as a whole, it is possible to calculate the amount of X elements in the steel able to effectively act to inhibit the recrystallization of austenite grains. Here, the maximum amount (atom%) of X elements able to be consumed for forming oxides ($X_2 O_3$), nitrides (XN), and sulfides (XS) can be approximately calculated as $(M_{[Fe]}/M_{[O]}) \times [O] \times 2/3$, $(M_{[Fe]}/M_{[N]}) \times [N]$, and $(M_{[Fe]}/M_{[S]}) \times [S]$ using the amounts of atoms of Fe, O, N, and S and the contents of O, N, and S in the steel due to reasons similar to those explained above. Therefore, the effective amount of X elements for inhibiting the recrystallization of austenite grains can be defined by the following formula A.

$$\text{Effective amount of X elements [atoms \%]} = \sum (M_{[Fe]}/M_{[X]}) \times [X] - (M_{[Fe]}/M_{[O]}) \times [O] \times 2/3 - (M_{[Fe]}/M_{[N]}) \times [N] - (M_{[Fe]}/M_{[S]}) \times [S] \quad \cdots \text{ formula A}$$

[0062] The amounts of atoms of Fe, O, N, and S and the X elements are respectively Fe: 55.845, O: 15.9994, N: 14.0069, S: 32.068, Pr: 140.908, Sm: 150.36, Eu: 151.964, Gd: 157.25, Tb: 158.925, Dy: 162.500, Ho: 164.930, Er: 167.259, Tm: 168.934, Yb: 173.045, Lu: 174.967, and Sc: 44.9559. Therefore, if entering the amounts of the atoms of the elements in the above formula A and cleaning it up, it becomes possible to approximately express the effective amount of the atom% of the X elements by the following formula B.

$$\begin{aligned} \text{Effective amount} = & 0.40[\text{Pr}] + 0.37[\text{Sm}] + 0.37[\text{Eu}] + 0.36[\text{Gd}] + 0.35[\text{Tb}] + 0.34[\text{Dy}] + \\ & 0.34[\text{Ho}] + 0.33[\text{Er}] + 0.33[\text{Tm}] + 0.32[\text{Yb}] + 0.32[\text{Lu}] + 1.24[\text{Sc}] - 2.33[\text{O}] - 3.99[\text{N}] - 1.74[\text{S}] \quad \cdots \\ & \text{formula B} \end{aligned}$$

where [Pr], [Sm], [Eu], [Gd], [Tb], [Dy], [Ho], [Er], [Tm], [Yb], [Lu], [Sc], [O], [N], and [S] are the contents [mass%] of the elements, and if the elements are not included, the contents are 0.

[0063] In an embodiment of the present invention, to inhibit the recrystallization of austenite grains, the effective amount of the X elements sought by the above formula B has to be 0.0003% or more, i.e., has to satisfy the following formula 1:

$$\begin{aligned} & 0.40[\text{Pr}] + 0.37[\text{Sm}] + 0.37[\text{Eu}] + 0.36[\text{Gd}] + 0.35[\text{Tb}] + 0.34[\text{Dy}] + 0.34[\text{Ho}] + 0.33[\text{Er}] + 0.33[\text{Tm}] \\ & + 0.32[\text{Yb}] + 0.32[\text{Lu}] + 1.24[\text{Sc}] - 2.33[\text{O}] - 3.99[\text{N}] - 1.74[\text{S}] \geq 0.0003 \quad \cdots \text{ formula 1} \end{aligned}$$

[0064] The effective amount of the X elements may, for example, be 0.0005% or more or 0.0007% or more, preferably 0.0010% or more, more preferably 0.0015% or more, still more preferably 0.0030% or more, most preferably 0.0050% or more or 0.0100% or more. Further, as clear also from the above formula 1, to stably secure the effective amount, it is preferable to reduce the contents of O, N, and S in the steel as much as possible. Here, no upper limit of the effective amount of the X elements is particularly prescribed, but even if excessively increasing the effective amount of the X elements, the effect becomes saturated and a rise in the production costs (rise of alloy cost accompanying increase of content of X elements and/or rise of refining cost relating to O, N, and S) is invited, therefore this is not necessarily preferable. Therefore, the effective amount of the X elements is preferably 2.0000% or less, for example, may be 1.8000% or less, 1.5000% or less, 1.2000% or less, 1.0000% or less, or 0.8000% or less.

[0065] The steel material according to an embodiment of the present invention may be any steel material and is not particularly limited. The steel material according to an embodiment of the present invention includes, for example, a steel material before exhibiting the effect of inhibition of recrystallization, for example, a steel material before hot rolling such as a slab, billet, or bloom, and a steel material after exhibiting the effect of inhibition of recrystallization, for example, a steel material after hot rolling. The steel material after hot rolling is not particularly limited, but, for example, includes thick steel plate, thin steel sheet, and steel bars, wire rods, steel shapes, steel pipes, etc.

[0066] The steel material according to an embodiment of the present invention can be produced by any suitable method known to persons skilled in the art according to the form of the final product, etc. For example, if the steel material is thick steel plate, the method of production includes steps applied when generally producing thick steel plate, for example, a step of casting a slab having the chemical composition explained above, a step of hot rolling the cast slab, wherein the hot rolling step includes finish rolling ending at a temperature lower than the recrystallization start temperature, and a step of cooling the obtained rolled material, and may further include as needed a suitable heat treatment step, a tempering step, etc. For example, the steel material according to an embodiment of the present invention is particularly suited for application of a thermo mechanical control process (TMCP) combining controlled rolling and accelerated cooling.

[0067] Further, if the steel material is thin steel sheet, the method of production includes steps applied when generally producing thin steel sheet, for example, a step of casting a slab having the chemical composition explained above, a step of hot rolling the cast slab, wherein the hot rolling step includes finish rolling ending at a temperature lower than the recrystallization start temperature, a step of coiling and coiling the obtained rolled material, and may further include as needed a cold rolling step and an annealing step, etc. In the method of production of steel bars and other steel materials as well, similarly, it may include steps which are generally applied when producing steel bars and other steel materials, for example, may include a steelmaking step forming steel melt having the chemical composition explained above, a step of casting a slab, billet, bloom, etc., from the steel melt formed, a step of hot rolling the cast slab, billet, bloom, etc., wherein the hot rolling step includes finish rolling ending at a temperature lower than the recrystallization start temperature, and a step of cooling the obtained rolled material. The other steps can be suitably selected and performed from suitable steps known to persons skilled in the art for producing these steel materials. The specific conditions of the above steps are not particularly limited. Suitable conditions may be suitably selected in accordance with the type of steel, the type of steel material, the shape, etc. In the production of the steel material according to an embodiment of the present invention, it is important to secure the effective amount of X elements. For this reason, it is extremely important to sufficiently reduce the contents of O, N, and S able to form inclusions with the X elements in the steel in the refining step.

[0068] Below, examples will be used to explain the present invention in more detail, but the present invention is not limited to these examples.

EXAMPLES

[0069] In the examples, first, molten steels having various chemical compositions were produced using a vacuum melting furnace and ingots of about 50 kg were produced by the ingot making method. The chemical compositions obtained by analyzing samples taken from the ingots obtained were as shown in Table 1. Next, columnar shaped test materials ($\phi 8$ mm $\times$ height 12 mm) obtained from the ingots were used to perform compression tests. The effects of inhibition of recrystallization of the steel materials were evaluated based on the softening ratios calculated from the results of the tests.

[0070] Specifically, in accordance with the test conditions of a compression test shown in FIG. 1, first, a columnar shaped test material was heated to 950 to 1300°C, then two compression tests were performed under the conditions of the processing temperature of 950°C, true strain $\varepsilon=0.4$, strain speed $\dot{\varepsilon}/t=5s^{-1}$, and time between passes of 10s (processing 1 and processing 2 in FIG. 1). The softening ratio was measured from the stress-strain curve measured by the processing 1 and processing 2. Explained in more detail, as shown in FIG. 2 (extracted from Naoki Maruyama et al., "Form of Nb at an Early Stage of Recovery and Recrystallization in Austenite of Hot-Deformed Steel", J. Japan Inst. Metals, Vol. 60, No. 11 (1996), pp. 1051 to 1057), if designating the yield stress at the time of the first and second compression as respectively σ_1 and σ_2 and designating the maximum stress at the time of the first compression as σ_m , the softening ratio X_S can be calculated from the following formula:

$$X_S = (\sigma_m - \sigma_2) / (\sigma_m - \sigma_1)$$

[0071] If recrystallization sufficiently proceeds between the first compression and the second compression, the stress-strain curves measured by the processing 1 and processing 2 exhibit similar behavior, therefore σ_2 becomes a value close to σ_1 and therefore the softening ratio X_S approaches 1. On the other hand, if progression of recrystallization is inhibited between the first compression and the second compression, the dislocation density increases and work hardening occurs at the time of the second compression, therefore the yield stress σ_2 becomes higher and as a result the softening ratio X_S approaches 0. Therefore, by measuring the softening ratio X_S of the steel material, it is possible to evaluate the effect of inhibition of recrystallization possessed by the steel material. In the examples, if the softening ratio X_S is 0.20 or less, the steel material was evaluated as having an improved effect of inhibition of recrystallization. The results are shown in the following Table 1.

[Table 1-1]

5

10

15

20

25

30

35

40

45

50

55

Table 1-1

No.	Chemical composition (mass%, balance: Fe and impurities)																							
	C	Si	Mn	P	S	Al	N	O	Nb	Ti	Ta	V	Cu	Ni	Cr	Mo	W	B	Co	Be	Ag	Zr	Hf	Ca
1	0.373	0.27	0.84	0.007	0.0051	0.061	0.0043	0.0024										0.0009		0.010				
2	0.043	0.34	1.51	0.025	0.0063	0.016	0.0217	0.0019					0.52	0.07	12.08									
3	0.061	1.29	2.48	0.008	0.0010	0.028	0.0028	0.0013	0.018	0.130														
4	0.518	1.76	0.31	0.008	0.0055	0.048	0.0033	0.0018		0.018			0.16	0.15	0.15	0.27								
5	0.487	1.62	0.30	0.014	0.0062	0.041	0.0028	0.0020		0.021			0.11	0.11	0.12	0.32								
6	0.045	0.29	1.35	0.028	0.0058	0.023	0.0193	0.0017					0.55	0.06	11.95									
7	0.367	1.58	0.76	0.010	0.0081	0.041	0.0037	0.0016																
8	0.047	0.21	1.41	0.009	0.0003	0.022	0.0034	0.0008	0.007	0.007			0.30	0.24		0.10								0.0002
9	0.176	0.27	1.63	0.005	0.0012	0.026	0.0026	0.0010	0.007	0.014				0.95	0.28			0.0010				0.0004		
10	0.001	0.01	0.12	0.010	0.0092	0.022	0.0033	0.0010		0.042								0.0006						
11	0.054	0.01	0.86	0.003	0.0009	0.032	0.0035	0.0014			0.021			7.53	0.38	0.36					0.021			
12	0.066	0.31	0.96	0.017	0.0009	0.013	0.0252	0.0012						8.05	18.90									
13	0.548	1.51	0.68	0.013	0.0121	0.028	0.0036	0.0029							0.70									
14	0.050	0.24	1.36	0.012	0.0004	0.024	0.0028	0.0011	0.013	0.010			0.26	0.30		0.13								0.0001
15	0.084	0.30	1.65	0.009	0.0021	0.028	0.0027	0.0016	0.018	0.009		0.06	0.24	0.19										0.0004
16	0.184	0.23	1.51	0.003	0.0011	0.028	0.0030	0.0012	0.011	0.010				1.02	0.23		0.21	0.0011						
17	0.051	0.20	1.34	0.006	0.0003	0.026	0.0023	0.0014	0.011	0.011			0.23	0.26		0.15								0.0004
18	0.060	1.15	2.42	0.011	0.0013	0.025	0.0022	0.0010	0.020	0.134														
19	0.007	0.10	0.16	0.020	0.0015	0.048	0.0105	0.0021	0.063	0.139		0.05	0.03	0.07	16.42	0.03		0.0009						
20	0.051	0.03	1.77	0.014	0.0011	0.025	0.0029	0.0010	0.009	0.013			0.27	0.32		0.18								
21	0.092	0.31	1.85	0.009	0.0025	0.021	0.0034	0.0016	0.038	0.144								0.0026						
22	0.328	1.79	0.73	0.009	0.0086	0.044	0.0028	0.0011																
23	0.114	0.32	2.02	0.011	0.0028	0.023	0.0022	0.0014	0.042	0.150								0.0030						
24	0.073	0.32	0.89	0.024	0.0012	0.024	0.0232	0.0011						8.81	19.01									
25	0.184	0.26	1.45	0.004	0.0009	0.026	0.0034	0.0015	0.014	0.017				1.14	0.27			0.0014						
26	0.087	0.29	1.71	0.011	0.0019	0.032	0.0033	0.0013	0.025	0.016		0.07	0.22	0.20			0.16					0.0004		0.0002
27	0.208	1.47	2.30	0.008	0.0030	0.018	0.0024	0.0008																
28	0.016	0.53	1.47	0.022	0.0021	0.016	0.0410	0.0029					0.20	12.24	16.21	2.34			0.19					
29	0.378	1.64	0.85	0.010	0.0093	0.048	0.0033	0.0014																
30	0.071	1.28	2.61	0.010	0.0011	0.030	0.0031	0.0012	0.021	0.119														

[Table 1-2]

Table 1-2

No.	Chemical composition (mass%, balance: Fe and impurities)																								
	C	Si	Mn	P	S	Al	N	O	Nb	Ti	Ta	V	Cu	Ni	Cr	Mo	W	B	Co	Be	Ag	Zr	Hf	Ca	
31	0.513	1.46	0.73	0.011	0.0133	0.026	0.0040	0.0017							0.76										
32	0.490	1.96	0.69	0.009	0.0200	0.043	0.0035	0.0011				0.14		0.58	0.23										
33	0.961	0.47	1.46	0.014	0.0020	0.001	0.0036	0.0014	0.032	0.041		0.06													
34	0.001	0.01	0.10	0.013	0.0107	0.020	0.0025	0.0009		0.040								0.0008							
35	0.055	0.06	1.82	0.007	0.0016	0.004	0.0022	0.0017	0.012	0.009			0.22	0.26		0.13									
36	0.500	1.67	0.33	0.012	0.0061	0.050	0.0036	0.0014		0.020			0.15	0.09	0.16	0.35									
37	0.494	1.63	0.78	0.009	0.0127	0.031	0.0039	0.0021							0.62										
38	0.041	0.43	0.52	0.031	0.0012	0.065	0.0250	0.0017							15.35										
39	0.004	0.12	0.11	0.014	0.0013	0.042	0.0096	0.0028	0.071	0.143		0.08	0.02	0.11	15.92	0.05		0.0011							
40	0.482	2.09	0.76	0.006	0.0219	0.046	0.0030	0.0014				0.16		0.54	0.20										
41	0.012	0.52	1.54	0.017	0.0011	0.023	0.0386	0.0032					0.19	11.72	17.33	2.48			0.17						
42	0.371	0.01	1.43	0.013	0.0014	0.033	0.0035	0.0008		0.019								0.0025							
43	0.002	0.11	0.13	0.019	0.0010	0.045	0.0091	0.0026	0.070	0.130		0.06	0.04	0.15	16.59	0.02		0.0014							
44	0.042	0.28	1.49	0.030	0.0075	0.019	0.0187	0.0026					0.50	0.08	13.23						0.067				
45	0.094	0.34	1.92	0.008	0.0027	0.019	0.0020	0.0013	0.037	0.147								0.0028							
46	0.544	1.56	0.28	0.011	0.0064	0.046	0.0031	0.0022		0.024			0.18	0.12	0.19	0.30									
47	0.086	0.32	1.75	0.008	0.0015	0.032	0.0023	0.0010	0.018	0.013		0.04	0.18	0.16						0.038				0.0003	
48	0.003	0.10	0.10	0.023	0.0018	0.041	0.0102	0.0024	0.077	0.126		0.04	0.05	0.12	17.48	0.04		0.0012							
49	0.050	0.01	0.80	0.006	0.0011	0.027	0.0022	0.0010						6.94	0.44	0.42									
50	0.008	0.55	1.43	0.026	0.0014	0.018	0.0426	0.0027					0.17	12.06	18.23	2.66			0.16						
51	0.336	0.01	1.25	0.008	0.0010	0.031	0.0023	0.0010		0.016								0.0022							
52	0.515	1.84	0.65	0.008	0.0194	0.037	0.0033	0.0016				0.15		0.48	0.19										
53	0.197	1.56	2.28	0.009	0.0031	0.016	0.0029	0.0013																	
54	0.014	1.66	0.90	0.046	0.0032	4.080	0.0110	0.0009	1.392	0.221			0.37	52.78		2.39									
55	0.044	0.37	0.57	0.036	0.0014	0.074	0.0263	0.0018							16.96										
56	0.065	1.22	2.51	0.013	0.0009	0.032	0.0024	0.0015	0.023	0.132															
57	0.039	0.28	0.47	0.032	0.0011	0.068	0.0274	0.0023							16.42										
58	0.040	0.63	3.82	0.028	0.0014	0.021	0.1311	0.0023					0.15						2.63						
59	0.053	0.17	1.46	0.008	0.0002	0.023	0.0019	0.0006	0.008	0.012			0.28	0.27		0.16								0.0004	
60	0.078	0.34	0.95	0.022	0.0021	0.017	0.0241	0.0014						8.12	19.84										

[Table 1-3]

5

10

15

20

25

30

35

40

45

50

55

Table 1-3

No.	Chemical composition (mass%, balance: Fe and impurities)																								
	C	Si	Mn	P	S	Al	N	O	Nb	Ti	Ta	V	Cu	Ni	Cr	Mo	W	B	Co	Be	Ag	Zr	Hf	Ca	
61	0.071	0.33	0.82	0.026	0.0015	0.028	0.0227	0.0009						7.78	17.50							0.0003			
62	0.046	0.01	0.72	0.005	0.0014	0.035	0.0031	0.0012						9.12	0.43										
63	0.398	0.66	0.81	0.009	0.0012	0.050	0.0028	0.0009	0.012	0.015								0.0016							
64	0.366	0.63	0.78	0.008	0.0014	0.053	0.0030	0.0014	0.015	0.013								0.0011							
65	0.352	0.01	1.31	0.007	0.0012	0.029	0.0030	0.0014		0.023								0.0017							
66	0.344	0.31	0.86	0.010	0.0053	0.067	0.0041	0.0022										0.0012							
67	0.102	0.26	1.74	0.007	0.0033	0.015	0.0031	0.0010	0.042	0.156								0.0032							
68	0.210	1.53	2.34	0.012	0.0027	0.024	0.0033	0.0012																	
69	0.426	0.58	0.86	0.006	0.0017	0.046	0.0024	0.0011	0.014	0.009								0.0014							
70	0.090	0.36	1.56	0.008	0.0024	0.003	0.0026	0.0009	0.020	0.010		0.05	0.21	0.17											
71	0.473	1.47	0.61	0.010	0.0117	0.033	0.0026	0.0024							0.71										
72	0.001	0.01	0.11	0.007	0.0101	0.018	0.0029	0.0012		0.037								0.0004							
73	0.360	1.67	0.81	0.013	0.0091	0.044	0.0034	0.0017																	
74	0.010	0.52	1.48	0.024	0.0018	0.027	0.1702	0.0031					0.23	12.71	17.21	2.50									
75	0.180	0.20	1.50	0.003	0.0070	0.026	0.0028	0.0008	0.010	0.013				0.93	0.22			0.0012							
76	0.095	0.34	1.63	0.007	0.0022	0.030	0.0023	0.0012	0.019	0.012		0.08	0.15	0.14										0.0003	
77	0.201	1.64	2.25	0.006	0.0040	0.020	0.0028	0.0011																	
78	0.357	0.01	1.41	0.006	0.0008	0.026	0.0025	0.0012		0.021								0.0021							
79	0.350	0.34	0.80	0.008	0.0046	0.075	0.0038	0.0021										0.0014							
80	0.036	0.25	1.45	0.026	0.0069	0.024	0.0200	0.0022					0.46	0.11	12.69										
81	0.371	0.59	0.76	0.011	0.0016	0.045	0.0021	0.0012	0.017	0.011								0.0012							
82	0.036	0.35	0.48	0.026	0.0008	0.062	0.0242	0.0014							17.34										
83	0.471	2.05	0.72	0.013	0.0215	0.042	0.0027	0.0018				0.19		0.53	0.13										
84	0.066	1.19	2.43	0.012	0.0012	0.033	0.0032	0.0014	0.021	0.142															
85	0.100	0.27	1.87	0.006	0.0031	0.022	0.0032	0.0014	0.041	0.148								0.0031							
86	0.087	0.33	1.69	0.008	0.0024	0.028	0.0034	0.0013	0.022	0.013		0.06	0.18	0.20										0.0003	
87	0.511	1.53	0.66	0.012	0.0131	0.027	0.0032	0.0029							0.73										
88	0.498	1.47	0.69	0.011	0.0114	0.032	0.0038	0.0026							0.65										
89	0.052	0.01	0.82	0.003	0.0017	0.032	0.0034	0.0016						7.37	0.39	0.44									
90	0.043	0.35	0.53	0.032	0.0014	0.061	0.0256	0.0017							16.25										
91	0.011	0.55	1.45	0.023	0.0013	0.022	0.0429	0.0032					0.18	12.49	17.77	2.67			0.16						

[Table 1-4]

5

10

15

20

25

30

35

40

45

50

55

Table 1-4

No.		Chemical composition (mass%, balance: Fe and impurities)																				Softening rate X _S	Remarks		
		Mg	La, Ce, Nd, Pm, Y	Sn	Sb	Te	Se	As	Bi	Pb	Pr	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu			Sc	Effective amount
1				0.041														0.0698	0.7764	0.0689	0.7997		0.5256	0.00	Ex.
2										0.6060	0.6033	0.3037	0.1506	0.1628	0.2165	0.7539	0.5053	0.3426	0.5005	0.6146	0.1224		1.7056	0.00	Ex.
3				0.082	0.095		0.042							0.7178									0.2353	0.01	Ex.
4																				0.1992			0.0368	0.02	Ex.
5																			0.4400	0.0661	0.4908	0.1663	0.5030	0.00	Ex.
6																	0.3291					0.0175	0.04	Ex.	
7	0.0044			0.037																0.7139			0.1959	0.01	Ex.
8									0.0494													0.0038	0.10	Ex.	
9									0.7044													0.2670	0.01	Ex.	
10													0.1539									0.0239	0.03	Ex.	
11					0.065	0.064					0.0672							0.5654					0.0061	0.07	Ex.
12																						0.0817	0.01	Ex.	
13																						0.0408	0.05	Ex.	
14																					0.0161	0.0055	0.08	Ex.	
15											0.6891											0.2368	0.01	Ex.	
16												0.0514										0.0023	0.14	Ex.	
17			0.065				0.019									0.4737	0.4230	0.5404	0.2309	0.1918	0.2713	0.1688	0.9040	0.00	Ex.
18										0.5941	0.1162	0.6309	0.6153	0.2207	0.2813	0.4804	0.7964					1.3212	0.00	Ex.	
19			0.055													0.2747						0.0440	0.02	Ex.	
20		Nd:0.0002										0.0878										0.0167	0.04	Ex.	
21															0.1051							0.0141	0.04	Ex.	
22								0.072													0.0279	0.0059	0.06	Ex.	
23													0.7907									0.2677	0.01	Ex.	
24																					0.0883	0.0123	0.03	Ex.	
25										0.3329	0.2824	0.2856	0.6299									0.5515	0.00	Ex.	
26										0.0881												0.0157	0.04	Ex.	
27			0.113							0.5666	0.3542	0.5034	0.0580	0.1107	0.6250	0.3470						1.5371	0.00	Ex.	
28			0.031	0.011															0.5245	0.4758		0.2374	0.0155	0.03	Ex.
29		La:0.0002 Pm:0.0002 Y:0.0003				0.055		0.020									0.6517	0.6473	0.4095	0.4805	0.3867	0.1151	0.9579	0.00	Ex.
30													0.0622									0.0053	0.09	Ex.	

[Table 1-5]

5

10

15

20

25

30

35

40

45

50

55

Table 1-5

Chemical composition (mass%, balance: Fe and impurities)																									Softening ratio X _S	Remarks
No.	Mg	La, Ce, Nd, Pm, Y	Sn	Sb	Te	Se	As	Bi	Pb	Pr	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Effective amount				
31																		0.1662					0.0118	0.05	Ex.	
32																						0.0475	0.0076	0.06	Ex.	
33	0.0028												0.2004									0.0201	0.0760	0.00	Ex.	
34																						0.0335	0.0109	0.04	Ex.	
35											0.2989	0.7883										0.0280	0.4215	0.00	Ex.	
36																						0.0306	0.0097	0.05	Ex.	
37																				0.2489			0.0371	0.02	Ex.	
38																						0.0921	0.0084	0.05	Ex.	
39		0.058																0.4709					0.1083	0.01	Ex.	
40																			0.7281	0.4411			0.3208	0.01	Ex.	
41												0.5031				0.3843		0.2619					0.7895	0.00	Ex.	
42										0.0891	0.4424	0.1798	0.4259	0.0731	0.1001	0.2599	0.6210	0.1626	0.0737	0.7904			1.0840	0.00	Ex.	
43		0.063																				0.0422	0.0082	0.05	Ex.	
44															0.6807								0.1377	0.01	Ex.	
45										0.7853	0.1564	0.6991	0.7273	0.2882		0.3418	0.7506	0.1894				0.2406	1.7024	0.00	Ex.	
46																				0.7127			0.1994	0.01	Ex.	
47															0.2488	0.3121	0.4460	0.3348	0.5016	0.3601		0.7100	0.00	Ex.		
48		0.069													0.1313		0.5705		0.2143				0.2521	0.01	Ex.	
49																						0.0320	0.0267	0.02	Ex.	
50																0.6651						0.0474	0.02	Ex.		
51																					0.3188	0.3821	0.00	Ex.		
52																		0.6786					0.1733	0.01	Ex.	
53	0.0056	Ce:0.0001	0.043					0.012							0.0646							0.0020	0.16	Ex.		
54																						0.3810	0.4209	0.00	Ex.	
55																		0.4277		0.1604			0.0809	0.01	Ex.	
56																					0.0204	0.0107	0.04	Ex.		
57																0.4977						0.0526	0.02	Ex.		
58										0.2101					0.4803							0.2557	0.0335	0.01	Ex.	
59		La:0.0002																				0.0079	0.0005	0.17	Ex.	
60											0.4315		0.6316		0.0641		0.7047		0.6958				0.7610	0.00	Ex.	

[Table 1-6]

5

10

15

20

25

30

35

40

45

50

55

Table 1-6

No.	Chemical composition (mass ⁹ %, balance: Fe and impurities)																					Softening		
	Mg	La, Ce, Nd, Pm, Y	Sn	Sb	Te	Se	As	Bi	Pb	Pr	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Effective amount	ratio X _S	Remarks
61																					0.7488	0.8332	0.00	Ex.
62										0.5963	0.7344	0.4046	0.5293	0.5571	0.2902							1.1266	0.00	Ex.
63																					0.0257	0.0165	0.03	Ex.
64												0.6734										0.2315	0.01	Ex.
65																					0.0224	0.0105	0.05	Ex.
66																		0.1507				0.0175	0.04	Ex.
67																					0.0336	0.0212	0.02	Ex.
68																					0.0256	0.0111	0.04	Ex.
69										0.4321		0.2992	0.5993	0.1091							0.0916	0.6360	0.00	Ex.
70																					0.0181	0.0058	0.07	Ex.
71										0.2153		0.7345		0.3758		0.2666		0.2236		0.3085	0.0263	0.7489	0.00	Ex.
72										0.4049	0.2028	0.5397		0.2913	0.3222	0.2243					0.0380	0.7396	0.00	Ex.
73																					0.0383	0.0141	0.03	Ex.
74												0.5028		0.6658		0.3832		0.2624			0.2535	0.2608	0.00	Ex.
75																					0.0278	0.0093	0.05	Ex.
76		La:0.0001 Ce:0.0001								0.5545	0.5467											0.4083	0.00	Ex.
77	0.0070													0.0966								0.0131	0.04	Ex.
78														0.0573								0.0059	0.07	Ex.
79																					0.0336	0.0136	0.03	Ex.
80																					0.0851	0.0086	0.05	Ex.
81											0.0846											0.0173	0.04	Ex.
82																	0.7633					0.1507	0.01	Ex.
83																				0.1803		0.0053	0.09	Ex.
84																						-0.0181	1.00	Comp. ex.
85																					0.0137	-0.0044	0.95	Comp. ex.
86																					0.0131	-0.0045	0.95	Comp. ex.
87																					0.0307	-0.0043	0.95	Comp. ex.
88																		0.0236				-0.0333	0.98	Comp. ex.
89																	0.0429					-0.0061	0.96	Comp. ex.
90															0.0848							-0.0797	0.99	Comp. ex.
91														0.2988								-0.0763	0.99	Comp. ex.

[0072] Referring to Table 1, in each of Comparative Examples 84 to 91, the effective amount of the X elements consisting of Pr, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Sc was low, therefore a sufficient effect of inhibition of recrystallization could not be exhibited. More specifically, in Comparative Example 84, X elements were not contained, therefore a sufficient effect of inhibition of recrystallization could not be exhibited. Further, in each of Comparative Examples 85 to 91, the X elements were included, but the contents were small in relation relative to O, N, and/or S. In other words, the contents of O, N, and/or S were excessive with respect to the X elements, therefore it is believed that a relatively large amount of inclusions were formed between the X elements and these elements. As a result, the effective amount of X elements became lower and sufficient a effect of inhibition of recrystallization could not be exhibited. In contrast to this, in all of the examples according to the present invention, high effects of inhibition of recrystallization could be exhibited by making the effective amounts of the X elements 0.0003% or more.

INDUSTRIAL APPLICABILITY

[0073] The steel material according to an embodiment of the present invention is, for example, a steel material before hot rolling such as a slab, billet, or bloom, or a steel material after hot rolling. As a steel material after hot rolling, for example, thick steel plate used for bridges, buildings, shipbuilding, pressure vessels, and other applications, thin steel sheet used for automobiles, household electric appliances, and other applications, and further steel bars, wire rods, steel shapes, steel pipes, etc., are also included. If applying the steel material according to an embodiment of the present invention in these materials, it is possible to produce the steel materials without impairing productivity due to the effect of inhibition of recrystallization. Further, it is possible to refine the metallic structure in the steel materials, therefore it is possible to remarkably improve the properties related in refinement of the metallic structures, for example, the toughness.

Claims

1. A steel material having a chemical composition consisting of, by mass%,

C: 0.001 to 1.000%,

Si: 0.01 to 3.00%,

Mn: 0.10 to 4.50%,

P: 0.300% or less,

S: 0.0300% or less,

Al: 0.001 to 5.000%,

N: 0.2000% or less,

O: 0.0100% or less,

at least one X element selected from the group consisting of Pr: 0 to 0.8000%, Sm: 0 to 0.8000%, Eu: 0 to 0.8000%, Gd: 0 to 0.8000%, Tb: 0 to 0.8000%, Dy: 0 to 0.8000%, Ho: 0 to 0.8000%, Er: 0 to 0.8000%, Tm: 0 to 0.8000%, Yb: 0 to 0.8000%, Lu: 0 to 0.8000%, and Sc: 0 to 0.8000%,

Nb: 0 to 3.000%,

Ti: 0 to 0.500%,

Ta: 0 to 0.500%,

V: 0 to 1.00%,

Cu: 0 to 3.00%,

Ni: 0 to 60.00%,

Cr: 0 to 30.00%,

Mo: 0 to 5.00%,

W: 0 to 2.00%,

B: 0 to 0.0200%,

Co: 0 to 3.00%,

Be: 0 to 0.050%,

Ag: 0 to 0.500%,

Zr: 0 to 0.5000%,

Hf: 0 to 0.5000%,

Ca: 0 to 0.0500%,

Mg: 0 to 0.0500%,

at least one of La, Ce, Nd, Pm, and Y: 0 to 0.5000% in total,

Sn: 0 to 0.300%,

Sb: 0 to 0.300%,

Te: 0 to 0.100%,
 Se: 0 to 0.100%,
 As: 0 to 0.050%,
 Bi: 0 to 0.500%,
 Pb: 0 to 0.500%, and
 balance: Fe and impurities, and
 satisfying the following formula 1:

$$0.40[\text{Pr}] + 0.37[\text{Sm}] + 0.37[\text{Eu}] + 0.36[\text{Gd}] + 0.35[\text{Tb}] + 0.34[\text{Dy}] + 0.34[\text{Ho}] + 0.33[\text{Er}] + 0.33[\text{Tm}] \\ + 0.32[\text{Yb}] + 0.32[\text{Lu}] + 1.24[\text{Sc}] - 2.33[\text{O}] - 3.99[\text{N}] - 1.74[\text{S}] \geq 0.0003 \quad \dots \text{ formula 1}$$

where [Pr], [Sm], [Eu], [Gd], [Tb], [Dy], [Ho], [Er], [Tm], [Yb], [Lu], [Sc], [O], [N], and [S] are the contents [mass%]
 of the elements, and if the elements are not included, the contents are 0.

2. The steel material according to claim 1, wherein the chemical composition contains, by mass%, one or more of

Nb: 0.003 to 3.000%,
 Ti: 0.005 to 0.500%,
 Ta: 0.001 to 0.500%,
 V: 0.001 to 1.00%,
 Cu: 0.001 to 3.00%,
 Ni: 0.001 to 60.00%,
 Cr: 0.001 to 30.00%,
 Mo: 0.001 to 5.00%,
 W: 0.001 to 2.00%,
 B: 0.0001 to 0.0200%,
 Co: 0.001 to 3.00%,
 Be: 0.0003 to 0.050%, and
 Ag: 0.001 to 0.500%.

3. The steel material according to claim 1 or 2, wherein the chemical composition contains, by mass%, one or more of

Zr: 0.0001 to 0.5000%,
 Hf: 0.0001 to 0.5000%,
 Ca: 0.0001 to 0.0500%,
 Mg: 0.0001 to 0.0500%, and
 at least one of La, Ce, Nd, Pm, and Y: 0.0001 to 0.5000% in total.

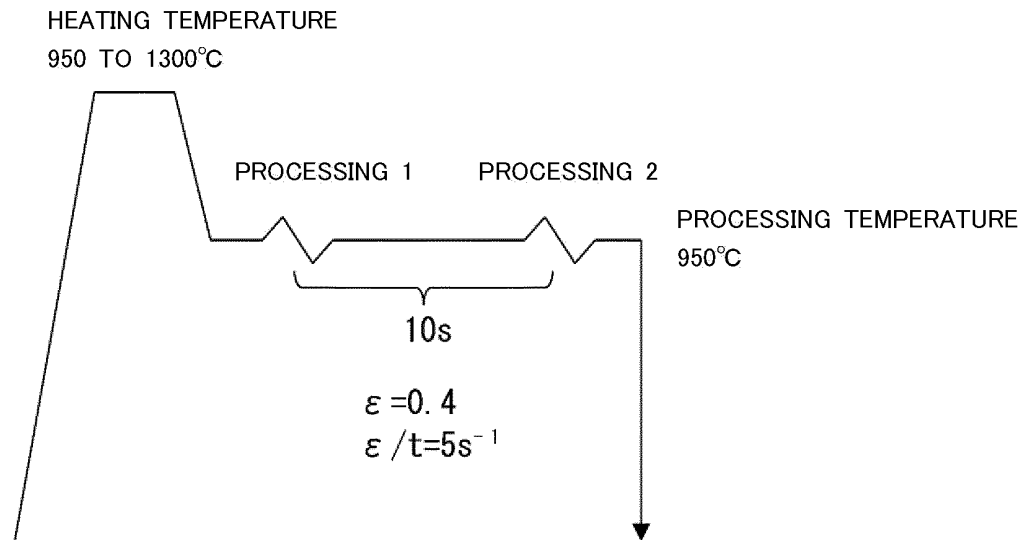
4. The steel material according to any one of claims 1 to 3, wherein the chemical composition contains, by mass%,
 one or both of

Sn: 0.001 to 0.300% and
 Sb: 0.001 to 0.300%.

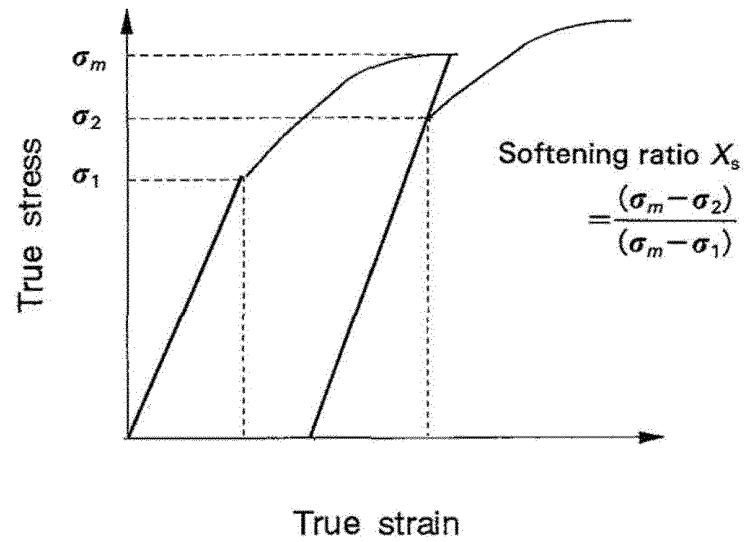
5. The steel material according to any one of claims 1 to 4, wherein the chemical composition contains, by mass%,
 one or more of

Te: 0.001 to 0.100%,
 Se: 0.001 to 0.100%,
 As: 0.001 to 0.050%,
 Bi: 0.001 to 0.500%, and
 Pb: 0.001 to 0.500%.

[FIG. 1]



[FIG. 2]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/014738

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; C22C 19/03(2006.01)i; C22C 19/05(2006.01)i; C22C 38/06(2006.01)i; C22C 38/60(2006.01)i
 FI: C22C38/00 301Z; C22C38/00 302Z; C22C38/06; C22C38/60; C22C19/05 Z; C22C19/03 Z

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00; C22C19/03; C22C19/05; C22C38/06; C22C38/60

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2006/112428 A1 (SUMITOMO METAL INDUSTRIES, LTD.) 26 October 2006 (2006-10-26) table 1	1-3
X	JP 2018-24908 A (NIPPON STEEL & SUMITOMO METAL CORPORATION) 15 February 2018 (2018-02-15) table 1, paragraph [0032]	1-5
X	JP 2020-186423 A (NIPPON STEEL CORPORATION) 19 November 2020 (2020-11-19) table 1	1-3
A	JP 2005-520934 A (PARK, Yong-Soo) 14 July 2005 (2005-07-14)	1-5
A	JP 2005-226150 A (DAIDO STEEL CO., LTD.) 25 August 2005 (2005-08-25)	1-5



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
 21 June 2021 (21.06.2021)

Date of mailing of the international search report
 29 June 2021 (29.06.2021)

Name and mailing address of the ISA/
 Japan Patent Office
 3-4-3, Kasumigaseki, Chiyoda-ku,
 Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/JP2021/014738

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
WO 2006/112428 A1	26 Oct. 2006	US 2008/0050205 A1 table 1 EP 1873270 A1 CA 2004428 A1 KR 10-2007-0110139 A CN 101103808 A KR 10-0915489 B1	
JP 2018-24908 A	15 Feb. 2018	(Family: none)	
JP 2020-186423 A	19 Nov. 2020	(Family: none)	
JP 2005-520934 A	14 Jul. 2005	JP 2011-174183 A US 2005/0158201 A1 WO 2003/080880 A1 EP 1803832 A1 DE 00313703 T2 KR 10-2003-0077239 A CN 1043170 A CN 101580917 A AU 2003221202 A1	
JP 2005-226150 A	25 Aug. 2005	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 58077528 A [0004]
- JP 63235430 A [0004]
- JP 63235431 A [0004]
- JP 2004269924 A [0004]

Non-patent literature cited in the description

- **NAOKI MARUYAMA et al.** Form of Nb at an Early Stage of Recovery and Recrystallization in Austenite of Hot-Deformed Steel. *J. Japan Inst. Metals*, 1996, vol. 60 (11), 1051-1057 [0010] [0070]