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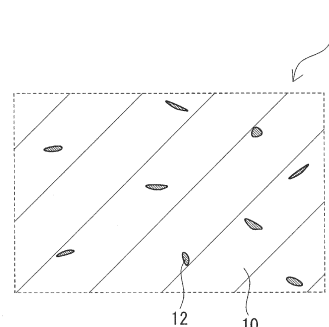
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(54) **IRON ALLOY, IRON ALLOY WIRE, AND IRON ALLOY STRANDED WIRE**

(57) An iron alloy includes: a composition including, in mass%, 0.1% or more and 0.4% or less of C, 0.2% or more and 2.0% or less of Si, 0.05% or more and 2.0% or less of Mn, 25% or more and 42% or less of Ni, 0.1% or more and 3.0% or less of Cr, 0.2% or more and 3.0% or less of V, 0% or more and 0.1% or less of a total of one or more elements selected from a group consisting of Ca, Ti, Al, and Mg, 0% or more and 0.1% or less of a total of one or more elements selected from a group consisting of Zr, Hf, Mo, Cu, Nb, Ta, W, and B, and 0% or more and 5% or less of Co, a remainder of the composition consisting of Fe and an inevitable impurity; and a structure having a matrix in which oxides are dispersed, wherein in a cross section of the iron alloy, a maximum diameter of the oxides included in a region of 2 mm × 20 mm is less than 150 μm.

FIG.1



Description

TECHNICAL FIELD

5 **[0001]** The present disclosure relates to an iron alloy, an iron alloy wire, and an iron alloy stranded wire. The present application claims a priority based on Japanese Patent Application No. 2020-133707 filed on August 6, 2020, the entire contents of which are incorporated herein by reference.

BACKGROUND ART

10 **[0002]** As described in each of PTL 1 and PTL 2, a steel wire including a predetermined amount of nickel has been conventionally used for a core wire of an overhead power transmission line. On an outer periphery of the core wire, an aluminum wire, which forms a conductor portion of the overhead power transmission line, is disposed.

15 CITATION LIST

PATENT LITERATURE

[0003]

20 PTL 1: Japanese Patent Laying-Open No. 2002-256395
PTL 2: WO 2018/193810

SUMMARY OF INVENTION

25 **[0004]** An iron alloy of the present disclosure includes:
a composition including, in mass%,
30 0.1% or more and 0.4% or less of C,
0.2% or more and 2.0% or less of Si,
0.05% or more and 2.0% or less of Mn,
25% or more and 42% or less of Ni,
0.1% or more and 3.0% or less of Cr,
35 0.2% or more and 3.0% or less of V,
0% or more and 0.1% or less of a total of one or more elements selected from a group consisting of Ca, Ti, Al,
and Mg,
0% or more and 0.1% or less of a total of one or more elements selected from a group consisting of Zr, Hf, Mo,
Cu, Nb, Ta, W, and B, and
40 0% or more and 5% or less of Co, a remainder of the composition consisting of Fe and an inevitable impurity; and
a structure having a matrix in which oxides are dispersed, wherein
in a cross section of the iron alloy, a maximum diameter of the oxides included in a region of 2 mm × 20 mm is less
than 150 μm.

45 **[0005]** An iron alloy wire of the present disclosure is composed of the iron alloy of the present disclosure.
[0006] An iron alloy stranded wire of the present disclosure includes a plurality of elemental wires stranded together,
wherein
at least one elemental wire of the plurality of elemental wires is the iron alloy wire of the present disclosure.

BRIEF DESCRIPTION OF DRAWINGS

[0007]

55 Fig. 1 is an enlarged cross sectional view schematically showing an iron alloy of an embodiment.
Fig. 2 is a perspective view of an overhead power transmission line including an iron alloy wire of the embodiment
and an iron alloy stranded wire of the embodiment.
Fig. 3 is a graph conceptually showing a relation between a particle diameter of a particle of an inclusion and a

floating velocity of the particle in the Stokes' law.

Fig. 4A is a diagram illustrating a state in a mold when a cooling rate during continuous casting is high.

Fig. 4B is a diagram illustrating a state in the mold when the cooling rate during continuous casting is low.

5 DETAILED DESCRIPTION

[Problem to be Solved by the Present Disclosure]

[0008] An iron alloy having an excellent high-temperature strength has been desired.

10 **[0009]** The core wire of the above-described overhead power transmission line is desired to have an excellent strength at room temperature in order to withstand weight and tension of the overhead power transmission line. On the other hand, the core wire is desired to have a low linear expansion coefficient in a temperature range during use thereof in order to reduce sagging of the overhead power transmission line thermally expanded due to an increased temperature during supply of power. Each of PTL 1 and PTL 2 described above deals with these requirements by adjusting the composition of the steel.

15 **[0010]** Recently, a power transmission capacity tends to be increased. Such an increased power transmission capacity leads to increased Joule heat of the overhead power transmission line. As a result, the temperature of the overhead power transmission line can become high such as 200°C or more or about 230°C. The aluminum wire, which is thermally expanded in response to the increased temperature during supply of power, is elongated more than a steel wire included in the core wire is elongated. Here, the both end portions of the overhead power transmission line are each fixed to a terminal. It is considered that since the aluminum wire is elongated as described above, the core wire is fed with force to be pulled toward each of the terminal sides. When this tensile force is large, the core wire is considered to be broken. Therefore, there has been desired an iron alloy that not only has a strength at room temperature but also is less likely to be broken even at a high temperature of 200°C or more, i.e., has an excellent high-temperature strength.

25 **[0011]** Further, the core wire is typically a stranded wire including a plurality of steel wires stranded together. Each of the steel wires is twisted during stranding in a manufacturing process. Each of the steel wires is desired to be less likely to be broken by the twisting, that is, the iron alloy is desired to have an excellent twisting characteristic.

30 **[0012]** Thus, one object of the present disclosure is to provide an iron alloy having an excellent high-temperature strength. Another object of the present disclosure is to provide an iron alloy wire and an iron alloy stranded wire, each of which has an excellent high-temperature strength.

[Advantageous Effect of the Present Disclosure]

35 **[0013]** Each of the iron alloy of the present disclosure, the iron alloy wire of the present disclosure, and the stranded wire of the present disclosure has an excellent high-temperature strength.

[Description of Embodiments]

40 **[0014]** By adjusting a content of oxygen as described in PTL 2, ductility can be suppressed from being decreased due to oxides. However, as shown in a test example described later, it is difficult to improve the high-temperature strength of the iron alloy by only adjusting the content of oxygen. The present inventors have obtained the following knowledge: the high-temperature strength of the iron alloy can be improved by controlling sizes of oxides. Moreover, the present inventors have obtained the following knowledge: the iron alloy with controlled oxide sizes also has an excellent twisting characteristic. Further, the present inventors have obtained the following knowledge: the sizes of the oxides can be controlled by solidifying a molten alloy under a specific condition. The iron alloy of the present disclosure is based on these pieces of knowledge. First, embodiments of the present disclosure will be listed and described.

(1) An iron alloy according to an embodiment of the present disclosure includes:

50 a composition including, in mass%,

0.1% or more and 0.4% or less of C,
0.2% or more and 2.0% or less of Si,
0.05% or more and 2.0% or less of Mn,
55 25% or more and 42% or less of Ni,
0.1% or more and 3.0% or less of Cr,
0.2% or more and 3.0% or less of V,
0% or more and 0.1% or less of a total of one or more elements selected from a group consisting of Ca,

Ti, Al, and Mg,

0% or more and 0.1% or less of a total of one or more elements selected from a group consisting of Zr, Hf, Mo, Cu, Nb, Ta, W, and B, and

0% or more and 5% or less of Co, a remainder of the composition consisting of Fe and an inevitable impurity; and

a structure having a matrix in which oxides are dispersed, wherein

in a cross section of the iron alloy, a maximum diameter of the oxides included in a region of 2 mm × 20 mm is less than 150 μm.

[0015] The iron alloy of the present disclosure includes the oxides. However, since the maximum diameter of the oxides is less than 150 μm, each of the oxides is less likely to become a starting point of cracking when tensile force is applied to the iron alloy of the present disclosure at the high temperature. Propagation of cracking due to the oxides is also less likely to occur. For these reasons, the iron alloy of the present disclosure has an excellent high-temperature strength.

[0016] Further, when the twisting by stranding or the like is applied to the iron alloy of the present disclosure, each of the oxides is less likely to become a starting point of cracking. Propagation of cracking due to the oxides is also less likely to occur. For these reasons, the iron alloy of the present disclosure also has an excellent twisting characteristic.

[0017] Since the iron alloy of the present disclosure has the above-described specific composition, the iron alloy of the present disclosure has an excellent strength at room temperature. It is considered that a steel wire having a high tensile strength at room temperature is likely to have a high tensile strength to some extent even when the tensile strength is decreased to some extent due to increased temperature. Also in view of these, the iron alloy of the present disclosure has an excellent high-temperature strength.

[0018] Since the iron alloy of the present disclosure has the above-described specific composition, the iron alloy of the present disclosure also has an excellent twisting characteristic as described below. A steel wire having a high tensile strength at room temperature is likely to have a low toughness. It is considered that due to the low toughness, the steel wire is likely to be broken when twisted, i.e., the twisting characteristic is likely to be decreased. On the other hand, in the case of the iron alloy having the above-described specific composition, it is considered that the decrease in twisting characteristic due to the low toughness is small.

[0019] Further, since the iron alloy of the present disclosure has the above-described specific composition, the linear expansion coefficient thereof is small not only at room temperature but also at the high temperature described above. Therefore, an amount of thermal expansion at the high temperature is likely to be small. The iron alloy of the present disclosure, which has such excellent high-temperature strength, twisting characteristic, and strength at room temperature and has a small linear expansion coefficient, is suitable as a material for applications in which these characteristics are desired, such as a material for a core wire of an overhead power transmission line. When the iron alloy of the present disclosure is used as the core wire of the overhead power transmission line, an amount of sagging of the overhead power transmission line can be made small because the amount of thermal expansion at the high temperature is small.

[0020] The iron alloy of the present disclosure can be manufactured by a manufacturing method including a casting step. In particular, in this manufacturing method, casting is performed under such a specific condition that a cooling rate in a temperature range of change from a liquid phase to a solid phase is relatively low. Here, from the viewpoint of mass production, the cooling rate is generally set to be high in a temperature range from molten temperature to room temperature in a conventional manufacturing method. As shown in a below-described test example, however, when the cooling rate in the temperature range of change from the liquid phase to the solid phase is high in the casting step, specifically, when the cooling rate is more than 10°C/min, the maximum diameter of the oxides becomes more than 150 μm. On the other hand, as shown in the below-described test example, when the casting is performed under the above-described specific condition, the maximum diameter of the oxides is less than 150 μm. Thus, it can be said that the above-described specific condition is a preferable condition for manufacturing of an iron alloy for applications in which improvement of high-temperature strength is desired, such as an iron alloy for a core wire of an overhead power transmission line in which Joule heat can be increased in response to the further increased power transmission capacity as described above.

[0021] (2) An exemplary embodiment of the iron alloy of the present disclosure is as follows: in the cross section, the number of the oxides included in a region of 2 mm × 3 mm is 500 or less.

[0022] Since the number of the oxides that can be a starting point of cracking is small and propagation of cracking due to the oxides is suppressed, the above-described embodiment is more excellent in high-temperature strength and twisting characteristic.

[0023] (3) An exemplary embodiment of the iron alloy of the present disclosure is as follows: a content of oxygen in the composition is 0.003 mass% or less.

[0024] Since the number of the oxides that can be a starting point of cracking is small, the above-described embodiment is more excellent in high-temperature strength and twisting characteristic.

[0025] (4) An exemplary embodiment of the iron alloy of the present disclosure is as follows:
a ratio σ_{300}/σ_{RT} of a tensile strength σ_{300} at 300°C to a tensile strength σ_{RT} at room temperature is 0.8 or more.

[0026] The above-described embodiment is excellent in high-temperature strength.

[0027] (5) An exemplary embodiment of the iron alloy of the present disclosure is as follows:

ten test pieces each having a shape of line and each having a length that is 100 times as large as a diameter of the test piece are taken from the iron alloy, and an average value of the respective numbers of times of twisting, at a rotation speed of 60 rpm, the test pieces with one end of each of the test pieces being fixed until breakage of the test pieces is 30 or more.

[0028] The above-described embodiment is excellent in twisting characteristic.

[0029] (6) An exemplary embodiment of the iron alloy of the present disclosure is as follows:

a tensile strength σ_{RT} of the iron alloy at room temperature is 1250 MPa or more.

[0030] The above-described embodiment is excellent in strength at room temperature.

[0031] (7) An exemplary embodiment of the iron alloy of the present disclosure is as follows:

an average linear expansion coefficient of the iron alloy at 30°C to 230°C is 4 ppm/°C or less.

[0032] In the above-described embodiment, an amount of thermal expansion is small in a range from the room temperature to a high temperature of 200°C or more.

[0033] (8) An exemplary embodiment of the iron alloy of the present disclosure is as follows:

a breaking elongation of the iron alloy at room temperature is 0.8% or more.

[0034] Since the above-described embodiment is excellent in elongation, breakage is less likely to occur even when twisted by stranding or the like or when bent or fed with vibration or the like.

[0035] (9) An exemplary embodiment of the iron alloy of the present disclosure is as follows:

a work-hardening coefficient of the iron alloy at room temperature is 0.7 or more.

[0036] Since the above-described embodiment is excellent in impact resistance, breakage is less likely to occur even when subjected to an impact.

[0037] (10) An iron alloy wire according to an embodiment of the present disclosure is composed of the iron alloy according to any one of (1) to (9) above.

[0038] Since the iron alloy wire of the present disclosure is composed of the iron alloy of the present disclosure, the iron alloy wire of the present disclosure has an excellent high-temperature strength. Also, since the iron alloy wire of the present disclosure is composed of the iron alloy of the present disclosure, the iron alloy wire of the present disclosure has an excellent twisting characteristic.

[0039] (11) An exemplary embodiment of the iron alloy wire of the present disclosure is as follows:

the iron alloy wire includes a wire material composed of the iron alloy, and a covering layer that covers an outer periphery of the wire material, wherein

the covering layer includes Al or Zn.

[0040] Since the wire material composed of the iron alloy of the present disclosure is used as a main component in the above-described embodiment, high-temperature strength and twisting characteristic are excellent, and corrosion caused by contact between different types of metals can be reduced by the covering layer as described later.

[0041] (12) An exemplary embodiment of the iron alloy wire of the present disclosure is as follows:

a wire diameter of the iron alloy wire is 2 mm or more and 5 mm or less.

[0042] The above-described embodiment can be used, for example, for an elemental wire included in a core wire portion of an overhead power transmission line.

[0043] (13) An iron alloy stranded wire according to an embodiment of the present disclosure includes a plurality of elemental wires stranded together, wherein

at least one elemental wire of the plurality of elemental wires is the iron alloy wire according to any one of (10) to (12) above.

[0044] Since the iron alloy stranded wire of the present disclosure includes the elemental wire composed of the iron alloy wire of the present disclosure, the iron alloy stranded wire of the present disclosure has an excellent high-temperature strength. Further, since the iron alloy stranded wire of the present disclosure includes the elemental wire composed of the iron alloy wire of the present disclosure, the iron alloy stranded wire of the present disclosure has an excellent twisting characteristic. Such an iron alloy stranded wire of the present disclosure is suitable for a core wire of an overhead transmission line.

[Details of Embodiments of the Present Disclosure]

[0045] Embodiments of the present disclosure will be specifically described below with reference to figures. In the figures, the same reference characters represent components having the same names.

[Iron Alloy]

[0046] Referring to Fig. 1, an iron alloy of an embodiment will be described.

[0047] An iron alloy 1 of the embodiment includes a composition including a below-described first group of elements in below-described specific ranges, a remainder of the composition consisting of Fe and an inevitable impurity. The composition may include one or more elements selected from a group consisting of a below-described second group and a below-described third group in below-described specific range(s). Alternatively, the composition may not include the element(s) of the group consisting of the second group and the third group.

[0048] The elements included in the first group are C (carbon), Si (silicon), Mn (manganese), Ni (nickel), Cr (chromium), and V (vanadium).

[0049] The elements included in the second group are Ca (calcium), Ti (titanium), Al (aluminum), and Mg (magnesium).

[0050] The elements included in the third group are Zr (zirconium), Hf (hafnium), Mo (molybdenum), Cu (copper), Nb (niobium), Ta (tantalum), W (tungsten), and B (boron).

[0051] Further, the composition may include Co (cobalt).

[0052] Further, iron alloy 1 of the embodiment has a structure having a matrix 10 in which oxides 12 are dispersed. In a cross section of iron alloy 1, a maximum diameter D of oxides 12 included in a region of 2 mm × 20 mm is less than 150 μm. Here, maximum diameter D of oxides 12 is the maximum value among the respective calculated diameters of oxides 12 included in the region. The diameter of each oxide 12 is defined as a diameter of a circle having the same area as the cross sectional area of oxide 12. A method of measuring maximum diameter D will be described later in detail.

[0053] Hereinafter, the composition, structure, and characteristics of iron alloy 1 will be described sequentially. It should be noted that Fig. 1 shows a cross section of an iron alloy wire 2, which is composed of iron alloy 1 of the embodiment shown in Fig. 2, along a line I-I. The cross section of Fig. 1 is an exemplary cross section obtained by cutting iron alloy wire 2 along a plane parallel to the axial direction of iron alloy wire 2.

(Composition)

[0054] In the description below, the content of each element is a mass ratio when iron alloy 1 is regarded as 100 mass%, and is indicated in mass%. Further, in the description below, when "strength" is simply stated, the "strength" mainly means a strength at room temperature. The strength here is mainly a mechanical characteristic represented by tensile strength.

[0055] Iron alloy 1 of the embodiment is an Fe-Ni alloy that is based on Fe and that includes a relatively large amount of Ni as described below. The linear expansion coefficient of the Fe-Ni alloy is lower than that in the case where Ni is not included. When such an Fe-Ni alloy further includes the elements of the first group or the like, the strength of iron alloy 1 is basically improved. The linear expansion coefficient of iron alloy 1 tends to be increased in response to increased contents of the elements of the first group or the like.

<First Group>

«C»

[0056] The content of C is 0.1% or more and 0.4% or less.

[0057] When the content of C is 0.1% or more, the strength of iron alloy 1 is increased by a strengthening effect due to solid solution and a strengthening effect due to precipitation hardening resulting from precipitation of carbides. The strength is likely to be improved when the content of C is more than 0.1%, 0.13% or more, 0.15% or more, or 0.18% or more.

[0058] When the content of C is 0.4% or less, decrease in ductility due to the improved strength is likely to be small. Since elongation is likely to be high, iron alloy 1 has an excellent twisting characteristic. Further, when the content of C is 0.4% or less, an increase in linear expansion coefficient due to the inclusion of C is likely to be small. Therefore, an amount of thermal expansion at a high temperature of 200°C or more is likely to be small. When the content of C is 0.38% or less or 0.36% or less, these effects are likely to be obtained.

[0059] When the content of C is 0.15% or more and 0.35% or less, the strengthening effect and the effect of maintaining an excellent twisting characteristic and suppressing an increase in linear expansion coefficient are likely to be obtained particularly in a balanced manner.

<<Si>>

[0060] The content of Si is 0.2% or more and 2.0% or less.

[0061] When the content of Si is 0.2% or more, the strength of iron alloy 1 is increased by the strengthening effect due to solid solution. When the content of Si is 0.3% or more and 0.4% or more, the strength is likely to be improved.

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When the content of Si is 0.5% or more, a strengthening effect by precipitation of a compound including Si or the like can be obtained in addition to the strengthening effect due to solid solution.

[0062] When the content of Si is 2.0% or less, an increase in linear expansion coefficient due to the inclusion of Si is likely to be small. When the content of Si is 1.8% or less, 1.6% or less, or 1.5% or less, the increase in linear expansion coefficient is further suppressed.

[0063] When the content of Si is 0.3% or more and 1.5% or less, the strengthening effect and the effect of suppressing the increase in linear expansion coefficient are likely to be obtained in a balanced manner.

<<Mn>>

[0064] The content of Mn is 0.05% or more and 2.0% or less.

[0065] When the content of Mn is 0.05% or more, an effect as a deoxidizer and a strengthening effect due to solid solution can be obtained excellently. When the content of Mn is 0.1% or more or 0.13% or more, these effects are more likely to be obtained.

[0066] When the content of Mn is 2.0% or less, an increase in linear expansion coefficient due to the inclusion of Mn is likely to be small. When the content of Mn is 1.8% or less, 1.5% or less, 1.2% or less, 1.0% or less, or 0.8% or less, the increase in linear expansion coefficient is further suppressed.

[0067] When the content of Mn is 0.05% or more and 1.2% or less, the deoxidizing effect, the strengthening effect, and the effect of suppressing the increase in linear expansion coefficient are likely to be obtained in a balanced manner.

<<Ni>>

[0068] The content of Ni is 25% or more and 42% or less.

[0069] When the content of Ni is 25% or more and 42% or less, the linear expansion coefficient of iron alloy 1 is likely to be small. When the content of Ni is 28% or more and 41% or less, 30% or more and 40% or less, or 33% or more and 40% or less, the linear expansion coefficient is likely to be smaller.

<<Cr>>

[0070] The content of Cr is 0.1% or more and 3.0% or less.

[0071] When the content of Cr is 0.1% or more, not only the strength at room temperature but also the high-temperature strength can be improved by a strengthening effect due to solid solution. When the content of Cr is 0.2% or more, 0.3% or more, or 0.5% or more, the strength at room temperature and the high-temperature strength are likely to be high. When the content of Cr is large to some extent, part of Cr is precipitated as a carbide. A strengthening effect by precipitation hardening of the carbide is obtained.

[0072] When the content of Cr is 3.0% or less, a coarse carbide is less likely to be formed. Therefore, a decrease in strength and a decrease in ductility due to such a coarse carbide are reduced. Since such an iron alloy 1 is excellent in strength and is likely to have a high elongation, iron alloy 1 also has an excellent twisting characteristic. Further, when the content of Cr is 3.0% or less, an increase in linear expansion coefficient due to the inclusion of Cr is likely to be small. When Cr is precipitated as a carbide as described above, the increase in linear expansion coefficient due to the inclusion of Cr is likely to be smaller. When the content of Cr is 2.8% or less, 2.6% or less, 2.0% or less, 1.8% or less, or 1.6% or less, these effects can be more likely to be obtained.

[0073] When the content of Cr is 0.5% or more and 2.0% or less, the strengthening effect and the effect of maintaining the excellent twisting characteristic and suppressing the increase in linear expansion coefficient are likely to be obtained in a balanced manner.

«V»

[0074] The content of V is 0.2% or more and 3.0% or less.

[0075] When the content of V is 0.2% or more, the strength of iron alloy 1 is increased by a strengthening effect due to precipitation hardening resulting from precipitation of a carbide. When the content of V is 0.3% or more, 0.4% or more, or 0.5% or more, the strength is likely to be improved.

[0076] When the content of V is 3.0% or less, an increase in linear expansion coefficient due to the inclusion of V is likely to be small. Since V is precipitated as a carbide as described above, the increase in linear expansion coefficient due to the inclusion of V is likely to be small. Further, when the content of V is 3.0% or less, a coarse carbide is less likely to be formed even in the case where there is a large amount of C. In view of this, iron alloy 1 is excellent in strength, elongation, and twisting characteristic due to the above reasons. When the content of V is 2.8% or less, 2.6% or less, or 2.0% or less, these effects can be more likely to be obtained.

[0077] When the content of V is 0.5% or more and 2.0% or less, the strengthening effect, the effect of suppressing the increase in linear expansion coefficient and maintaining the excellent twisting characteristic can be likely to be obtained in a balanced manner.

«V/C»

[0078] In iron alloy 1 of the embodiment, a ratio (V/C) of the content of V to the content of C is 2 or more and 9 or less. When the ratio (V/C) is 2 or more and 9 or less, V is likely to be precipitated as a carbide. Therefore, the strengthening effect by the precipitation hardening due to the precipitation of carbide is likely to be obtained excellently. Further, by the precipitation of the carbide including V, the increase in linear expansion coefficient due to the inclusion of C and the inclusion of V is likely to be small. Further, when the ratio (V/C) is 9 or less, a coarse carbide is less likely to be formed. In view of this, iron alloy 1 is excellent in strength, elongation, and twisting characteristic due to the above reasons. When the ratio (V/C) is 2.5 or more and 8.5 or less, 2.7 or more and 8 or less, or 3 or more and 5 or less, these effects are more likely to be obtained.

<<Cr/C>>

[0079] In iron alloy 1 of the embodiment, a ratio (Cr/C) of the content of Cr to the content of C is 0.3 or more and 10 or less. When the ratio (Cr/C) is 0.3 or more and 10 or less, Cr is likely to be precipitated as a carbide. Therefore, the increase in linear expansion coefficient due to the inclusion of Cr is likely to be small. Further, the strength can be expected to be improved due to precipitation hardening. Further, when the ratio (Cr/C) is 10 or less, a coarse carbide is less likely to be formed. In view of this, iron alloy 1 is excellent in strength, elongation, and twisting characteristic due to the above reasons. When the ratio (Cr/C) is 0.5 or more and 10 or less, 2 or more and 10 or less, or 2 or more and 7.5 or less, these effects are more likely to be obtained.

<<V+Cr>>

[0080] In iron alloy 1 of the embodiment, a total amount (V+Cr) of the content of V and the content of Cr is 0.5% or more and 5% or less. When the total amount (V+Cr) is 0.5% or more and 5% or less, the strengthening effect due to the precipitation hardening based on the carbide including V or the strengthening effect due to the inclusion of V, and the strengthening effect due to the precipitation hardening based on the carbide including Cr or the strengthening effect due to the inclusion of Cr are likely to be obtained excellently. In view of this, iron alloy 1 has an excellent strength. Further, by the precipitation of carbide, the increase in linear expansion coefficient is likely to be small as described above and the decrease in toughness is reduced as compared with a case where V and Cr are dissolved in a solid state. Further, when the total amount (V+Cr) is 5% or less, a coarse carbide is less likely to be formed. In view of this, iron alloy 1 is excellent in strength, elongation, and twisting characteristic due to the above reasons. When the total amount (V+Cr) is 0.8% or more and 5% or less, 1% or more and 5% or less, or 1% or more and 4% or less, these effects are more likely to be obtained.

<<(V+Cr)/C>>

[0081] In iron alloy 1 of the embodiment, a ratio ((V+Cr)/C) of the total amount (V+Cr) of the content of V and the content of Cr to the content of C is 4 or more and 15 or less. When the ratio ((V+Cr)/C) is 4 or more and 15 or less, the effects described in the respective sections "Ratio (V/C)" and "Ratio (Cr/C)" can be obtained excellently. When the ratio ((V+Cr)/C) is 4.2 or more and 14.8 or less, 4.5 or more and 14.5 or less, or 5 or more and 12 or less, the effects such as the strengthening effect, the suppression of increase in linear expansion coefficient, the maintaining of excellent twisting characteristic, and the like are more likely to be obtained.

<Second Group>

[0082] In iron alloy 1 of the embodiment, the content of a total of one or more elements selected from the second group consisting of Ca, Ti, Al, and Mg is 0% or more and 0.1% or less. The element(s) of the second group are each typically added as a deoxidizer. When the content of the second group is 0.1% or less in total, an amount of oxides 12 each including the element(s) of the second group are likely to be small. In view of this, decrease in strength, decrease in high-temperature strength, and decrease in twisting characteristic due to oxides 12 are likely to be reduced. When the content of the second group is more than 0% and 0.08% or less or 0.01% or more and 0.06% or less in total, a deoxidizing effect is likely to be obtained while reducing oxides 12.

<Third Group>

[0083] In iron alloy 1 of the embodiment, the content of a total of one or more elements selected from the third group consisting of Zr, Hf, Mo, Cu, Nb, Ta, W, and B is 0% or more and 0.1% or less. The element(s) of the third group each have a strengthening effect. When the content of the third group is 0.1% or less in total, decrease in ductility is likely to be small. Since elongation is likely to be high, iron alloy 1 also has an excellent twisting characteristic. Further, when the content of the third group is 0.1% or less in total, an increase in linear expansion coefficient due to the inclusion of the third group is likely to be small. When the content of the third group is more than 0% and 0.09% or less or 0.01% or more and 0.08% or less in total, the strengthening effect and the effect of maintaining the excellent twisting characteristic and suppressing the increase in linear expansion coefficient are likely to be obtained in a balanced manner.

<Co>

[0084] Iron alloy 1 of the embodiment may include Co. The content of Co is, for example, 0% or more and 5% or less. The content of Co may be 4% or less, 3% or less, 2% or less, or 1% or less. When Co is included in the range of more than 0% and 5% or less, the linear expansion coefficient of iron alloy 1 is likely to be small as in the case of Ni.

<Inevitable Impurity>

[0085] The inevitable impurity here is an element other than the elements of the first group, the elements of the second group, the elements of the third group, and Co. Examples of the inevitable impurity include O (oxygen).

<O>

[0086] O included in iron alloy 1 of the embodiment typically exists as oxides 12. Details of oxides 12 will be described later. The content of O is, for example, 0.003% or less. When the content of O is 0.003% or less, the total amount of oxides 12 included in iron alloy 1 is likely to be small. In view of this, decrease in strength, decrease in high-temperature strength, and decrease in twisting characteristic due to oxides 12 are likely to be reduced. Since the total amount of oxides 12 is smaller as the content of O is smaller, the content of O may be 0.002% or less or 0.001% or less. It should be noted that since iron alloy 1 of the embodiment includes oxides 12, the content of O is more than 0%.

(Structure)

[0087] Iron alloy 1 of the embodiment includes oxides 12 in matrix 10. Matrix 10 is mainly composed of steel having the above-described specific composition. Each of oxides 12 is a compound of oxygen and an element other than oxygen. Examples of the element other than oxygen include the element described in the above-described section "Composition", such as the element having a deoxidizing effect. In the description below, the "region of 2 mm × 20 mm" in the cross section of iron alloy 1 will be referred to as "first observation region".

<Oxides>

<<Maximum Diameter D>>

[0088] In iron alloy 1 of the embodiment, maximum diameter D of oxides 12 in the first observation region is less than 150 μm. Here, the first observation region is taken from an arbitrary cross section of iron alloy 1. Therefore, maximum diameter D of oxides 12 existing at an arbitrary position of iron alloy 1 of the embodiment is less than 150 μm. Further, when maximum diameter D is less than 150 μm, each of oxides 12 is less likely to become a starting point of cracking in the case where tensile force is applied to iron alloy 1 at a high temperature of 200°C or more. In view of this, iron alloy 1 has an excellent high-temperature strength. When maximum diameter D is less than 150 μm, each of oxides 12 is less likely to become a starting point of cracking in the case where twisting by stranding or the like is applied to iron alloy 1. In view of this, iron alloy 1 has an excellent twisting characteristic. When maximum diameter D is 140 μm or less, 120 μm or less, 100 μm or less, 90 μm or less, 70 μm or less, or 30 μm or less, each of oxides 12 is less likely to become a starting point of cracking, which is therefore preferable.

[0089] A smaller maximum diameter D is more preferable. However, when maximum diameter D is 5 μm or more or 10 μm or more, iron alloy 1 is readily manufactured.

[0090] When maximum diameter D is 5 μm or more and less than 150 μm or 10 μm or more and 100 μm or less, iron alloy 1 is excellent in high-temperature strength, is excellent in twisting characteristic, and is excellent in manufacturability.

<<Number Density>>

[0091] It is preferable that maximum diameter D of oxides 12 in iron alloy 1 is small and the number of oxides 12 is small. Quantitatively, the number of oxides 12 included in a region of 2 mm × 3 mm in the cross section of iron alloy 1 is 500 or less. In the description below, the "region of 2 mm × 3 mm" in the cross section of iron alloy 1 will be referred to as "second observation region". Further, the number of oxides 12 included in the second observation region will be referred to as "number density". A method of measuring the number density will be described later in detail.

[0092] When the number density is 500 or less, the number of oxides 12 that each can become a starting point of cracking is small. Further, propagation of cracking by the plurality of oxides 12 is suppressed. In such an iron alloy 1, cracking due to oxides 12 is less likely to occur. In view of this, iron alloy 1 is more excellent in high-temperature strength and twisting characteristic. When the number density is 400 or less, 300 or less, 200 or less, or 150 or less, cracking due to oxides 12 is much less likely to occur.

[0093] A smaller number density is more preferable. However, when the number density is 5 or more, 10 or more, or 15 or more, iron alloy 1 is manufactured readily.

[0094] When the number density is 5 or more and 500 or less or 10 or more and 200 or less, propagation of cracking is likely to be suppressed, so that iron alloy 1 is excellent in high-temperature strength, is excellent in twisting characteristic, and is excellent in manufacturability.

<Measuring Methods>

<<Maximum Diameter D>>

[0095] Maximum diameter D of oxides 12 is measured as follows.

(1) An arbitrary cross section is taken from iron alloy 1. The cross section is taken to sample the first observation region of 2 mm × 20 mm. For example, when iron alloy 1 is a wire material, a cross section obtained by cutting the wire material along a plane parallel to the axial direction of the wire material, i.e., a so-called longitudinal cross section is obtained. For example, when iron alloy 1 is a plate material, a cross section obtained by cutting the plate material along a plane parallel to the surface of the plate material is taken.

(2) The first observation region is observed using a scanning electron microscope (SEM). An observation magnification is set to 200x.

[0096] Oxides 12 existing in the first observation region are extracted. The cross sectional area of each of extracted oxides 12 is calculated. The diameter of a circle having the same area as the cross sectional area of each oxide 12 is defined as the diameter of oxide 12. The maximum value among the respective diameters of oxides 12 is defined as maximum diameter D of oxides 12. Here, a plurality of cross sections are taken, and respective first observation regions are taken from the cross sections. Maximum diameter D of oxides 12 is calculated for each of the first observation regions. The average of the plurality of calculated maximum diameters D is defined as maximum diameter D of oxides 12 in iron alloy 1.

[0097] It should be noted that oxides 12 each having a diameter of 1 μm or more are used for evaluation of maximum diameter D. That is, among all the oxides 12 existing in the first observation region, oxides 12 each having a diameter of less than 1 μm are not used for the evaluation of maximum diameter D. This is due to the following reason: it is considered that oxides 12 each having a diameter of less than 1 μm are less likely to become starting points of cracking.

<<Number Density>>

[0098] The number density of oxides 12 is measured as follows.

[0099] From the first observation region described above, the second observation region of 2 mm × 3 mm is taken. The total number of oxides 12 existing in the second observation region is calculated. The total number of calculated oxides 12 is defined as the number density. Here, the second observation region is taken from each of the plurality of first observation regions. The number density of oxides 12 is calculated for each second observation region. The average of the plurality of calculated number densities is defined as the number density in iron alloy 1. Also in the evaluation of the total number of oxides 12, as with the evaluation of maximum diameter D, oxides 12 each having a diameter of 1 μm or more are used, and oxides 12 each having a diameter of less than 1 μm are not used.

[0100] Extraction of oxides 12, calculation of the diameters and maximum diameter D of oxides 12, measurement of the number of oxides 12, and the like can be readily performed by using commercially available image processing device, software, or the like.

(Characteristics)

<Characteristics at Room Temperature>

[0101] Here, the room temperature is $20^{\circ}\text{C} \pm 15^{\circ}\text{C}$. In this temperature range, i.e., in a temperature range of 5°C or more and 35°C or less, below-described characteristics are not substantially changed. For example, a tensile strength at 5°C and a tensile strength at 35°C are substantially the same.

«Tensile Strength»

[0102] Since iron alloy 1 of the embodiment has the above-described specific composition, iron alloy 1 of the embodiment has an excellent strength at room temperature. Quantitatively, a tensile strength σ_{RT} at room temperature is 1250 MPa or more. When tensile strength σ_{RT} is 1250 MPa or more, iron alloy 1 has an excellent strength. For example, when a core wire portion 50 (Fig. 2) of an overhead power transmission line 5 is composed of iron alloy 1, core wire portion 50 withstands the weight and tension of overhead power transmission line 5. Further, iron alloy 1 having high tensile strength σ_{RT} is likely to have a high tensile strength to some extent even when the tensile strength is decreased to some extent in response to an increase in temperature. For example, when core wire portion 50 is composed of iron alloy 1, core wire portion 50 is likely to have a high tensile strength even at a high temperature of 200°C or more. In view of these points, iron alloy 1 is suitable for a material of core wire portion 50. When tensile strength σ_{RT} is 1300 MPa or more or 1350 MPa or more, iron alloy 1 has a more excellent strength.

[0103] When tensile strength σ_{RT} at room temperature is, for example, 1250 MPa or more and 1700 MPa or less or 1300 MPa or more and 1600 MPa or less, iron alloy 1 has an excellent strength and is likely to have high elongation, and therefore has an excellent twisting characteristic.

<<Breaking Elongation>>

[0104] In iron alloy 1 of the embodiment, a breaking elongation at room temperature is 0.8% or more. When the breaking elongation at room temperature is 0.8% or more, iron alloy 1 has an excellent elongation. For example, when an elemental wire 30 (Fig. 2) of an iron alloy stranded wire 3 is composed of iron alloy 1, each elemental wire 30 is less likely to be broken even when twisted during stranding in the manufacturing process. Further, for example, when core wire portion 50 of overhead power transmission line 5 is composed of iron alloy 1, breakage is less likely to occur even when subjected to strong wind, accumulation of snow, vibration, or the like after being installed overhead. In view of this point, iron alloy 1 is suitable for a material of elemental wire 30 of the iron alloy stranded wire 3 used for core wire portion 50 or the like. When the breaking elongation at room temperature is 0.9% or more or 1.0% or more, iron alloy 1 has a more excellent elongation.

[0105] When the breaking elongation at room temperature is, for example, 0.8% or more and 10% or less or 0.8% or more and 5% or less, iron alloy 1 has the above-described high strength and also has an excellent elongation.

<<Work-Hardening Coefficient>>

[0106] In iron alloy 1 of the embodiment, a work-hardening coefficient at room temperature is 0.7 or more. Here, the work-hardening coefficient is a value obtained by dividing 0.2% proof stress by the tensile strength, i.e., (0.2% proof stress/tensile strength). Between iron alloys having the same tensile strength and the same elongation, an iron alloy having a work-hardening coefficient of 0.7 or more has a below-described area larger than that of an iron alloy having a work-hardening coefficient of less than 0.7 in a graph representing a stress-strain curve during tensile test. The area is an area surrounded by the stress-strain curve, the horizontal axis, and a straight line that is parallel to the vertical axis and that passes through a strain value corresponding to a time of breakage of the iron alloy. It should be noted that in the graph, the horizontal axis represents strain and the vertical axis represents stress. It can be said that iron alloy 1 having the above-described large area has a high ability to absorb impact energy, i.e., has an excellent impact resistance. Hence, for example, when core wire portion 50 of overhead power transmission line 5 is composed of iron alloy 1, core wire portion 50 is less likely to be broken even when overhead power transmission line 5 receives an impact such as application of an abrupt load resulting from a gust of wind or the like. Further, in the case of an iron alloy having the same tensile strength, as the 0.2% proof stress is higher, in other words, as the work-hardening coefficient is higher, adhesion between core wire portion 50 and a terminal portion tends to be more excellent. In view of these points, iron alloy 1 is suitable for a material of elemental wire 30 of iron alloy stranded wire 3 used for core wire portion 50 or the like of overhead power transmission line 5. When the work-hardening coefficient is 0.8 or more or 0.9 or more, iron alloy 1 is less likely to be broken under application of impact as described above. It should be noted that the maximum value of the work-hardening coefficient here is 1.

«Twisting Characteristic»

[0107] In iron alloy 1 according to the embodiment, since maximum diameter D of oxides 12 is small as described above, cracking starting from an oxide 12 is less likely to occur even when twisted. Since iron alloy 1 of the embodiment has the above-described specific composition, iron alloy 1 of the embodiment is less likely to be broken by twisting. Quantitatively, the below-described average number of times is 30 or more. From iron alloy 1, ten test pieces each having a shape of line and each having a length that is 100 times as large as the diameter of the test piece are taken. The test pieces are twisted at a rotation speed of 60 rpm with one end of each of the test pieces being fixed so as to measure the respective numbers of times of twisting the test pieces until breakage of the test pieces. The average number of times is an average value of the respective numbers of times of twisting the test pieces. When the average number of times is 30 or more, it can be said that iron alloy 1 has an excellent twisting characteristic. For example, when elemental wire 30 of iron alloy stranded wire 3 is composed of iron alloy 1, each of elemental wires 30 is less likely to be broken by twisting during stranding as described above. Further, when the average number of times is 30 or more, a degree of freedom in setting a stranding condition is increased, thereby facilitating manufacturing of iron alloy stranded wire 3. In view of these points, iron alloy 1 is suitable for a material of elemental wire 30 of iron alloy stranded wire 3 used for core wire portion 50 or the like of overhead power transmission line 5. When the average number of times is 35 or more or 40 or more, iron alloy 1 has a more excellent twisting characteristic.

[0108] The diameter of each of the test pieces each having a shape of line is defined as follows.

[0109] A cross section of each of the test pieces is taken by cutting the test piece along a plane orthogonal to the axial direction of the test piece. The diameter of the test piece is defined as a diameter of a circle having the same area as the cross sectional area of the test piece in the cross section. When the test piece is a round wire, the diameter of the test piece corresponds to the outer diameter of the round wire.

[0110] The test piece having a shape of line is sampled to have a length that is 100 times as large as the diameter of the test piece. For example, when iron alloy 1 is a long wire material, the wire material may be cut to have a length that is 100 times as large as the diameter of the wire material.

[0111] The test piece having a shape of line has a below-described vertical distance of 10 mm or less. That is, for evaluation of the twisting characteristic, test pieces each having a below-described vertical distance of 10 mm or less are used. Each of the test pieces each having the above-described predetermined length is placed on a horizontal table. In this state, a vertical distance from the surface of the horizontal table to the highest point of the test piece is measured. Test pieces each having a measured vertical distance of 10 mm or less are used for the evaluation of twisting characteristic.

[0112] Here, for example, when iron alloy 1 is an elemental wire included in a stranded wire, the elemental wire is considered to have a tendency toward being stranded. Further, for example, when iron alloy 1 is a long wire material and is wound in the form of a coil, the wire material may be curved. When the test piece has a large tendency toward being stranded or is greatly curved, i.e., when the test piece is inferior in straightness, it is difficult to twist the test piece appropriately. As a result, the twisting characteristic is not appropriately evaluated. Therefore, after sampling the test piece having the predetermined length, the tendency toward being stranded, curve, and the like of the test piece are corrected, and then the twisting characteristic is evaluated. Quantitatively, the test piece may be corrected to have the above-described vertical distance of 10 mm or less. It should be noted that the vertical distance is measured regardless of whether or not there is the tendency toward being stranded. When the vertical distance is 10 mm or less, the test piece may not be corrected. However, it is preferable to correct the test piece to attain a smaller vertical distance.

<Characteristic at High Temperature>

<<High-Temperature Strength>>

[0113] In iron alloy 1 of the embodiment, since maximum diameter D of oxides 12 is small as described above, cracking starting from oxides 12 is less likely to occur even at a high temperature of 200°C or more. Also, since iron alloy 1 of the embodiment has the above-described specific composition, iron alloy 1 of the embodiment is likely to have a high tensile strength at the above-described high temperature.

Quantitatively, a ratio σ_{300}/σ_{RT} of a tensile strength σ_{300} at 300°C to a tensile strength σ_{RT} at room temperature is 0.8 or more. Hereinafter, ratio σ_{300}/σ_{RT} may be referred to as a high-temperature strength ratio. When the high-temperature strength ratio is 0.8 or more, it can be said that a high tensile strength σ_{300} is attained even at a high temperature of 300°C. That is, it can be said that iron alloy 1 has an excellent high-temperature strength. When the high-temperature strength ratio is 0.82 or more, 0.85 or more, or 0.90 or more, iron alloy 1 has a more excellent high-temperature strength. It should be noted that the high-temperature strength ratio is less than 1.

<Other Characteristic>

<<Linear Expansion Coefficient>>

[0114] Since iron alloy 1 of the embodiment has the above-described specific composition, the linear expansion coefficient is small in the range from the room temperature to the high temperature of 200°C or more. Quantitatively, the average linear expansion coefficient at 30°C to 230°C is 4 ppm/°C or less. When the average linear expansion coefficient is 4 ppm/°C or less ($4 \times 10^{-6}/^{\circ}\text{C}$ or less), it can be said that an amount of thermal expansion of iron alloy 1 is small even when a usage temperature can become about 200°C. When the average linear expansion coefficient is 3.9 ppm/°C or less, 3.8 ppm/°C or less, or 3.5 ppm/°C or less, the amount of thermal expansion of iron alloy 1 is smaller even at the high temperature. A method of measuring the average linear expansion coefficient will be described later.

[0115] In iron alloy 1 having the above-described specific composition, the average linear expansion coefficient is typically 1.0 ppm/°C or more.

(Applications)

[0116] Iron alloy 1 of the embodiment can be used for materials of various iron alloy products. Typical forms of iron alloy 1 include a wire material and a plate material. In particular, iron alloy 1 can be suitably used as a material for applications in which an excellent high-temperature strength is desired and an excellent twisting characteristic is desired. Examples of the applications include core wire portion 50 of overhead power transmission line 5 shown in Fig. 2.

[Iron Alloy Wire and Iron Alloy Stranded Wire]

[0117] Referring to Fig. 2, an iron alloy wire of the embodiment and an iron alloy stranded wire of the embodiment will be described.

[0118] Iron alloy wire 2 of the embodiment is typically a wire material composed of iron alloy 1 of the embodiment. Iron alloy wire 2 of the embodiment may further include a covering layer 22 in addition to the wire material. Fig. 2 illustrates iron alloy wire 2 including covering layer 22. Iron alloy stranded wire 3 of the embodiment includes a plurality of elemental wires 30 stranded together. At least one elemental wire 30 of the plurality of elemental wires 30 is iron alloy wire 2 of the embodiment. Fig. 2 illustrates a case where all the elemental wires 30 included in iron alloy stranded wire 3 are iron alloy wires 2 of the embodiment.

[0119] The cross sectional shape, the wire diameter, and the like of iron alloy wire 2 can be appropriately selected depending on its application and the like. The number of elementary wires, a strand pitch, and the like in iron alloy stranded wire 3 can be appropriately selected depending on its application and the like. Examples of the cross sectional shape include a circular shape, an elliptical shape, a quadrangular shape, and the like. The wire diameter is, for example, 2 mm or more and 5 mm or less. Here, the wire diameter is defined as a diameter of a circle having the same area as the cross sectional area of iron alloy wire 2 in a cross section of iron alloy wire 2 along a plane orthogonal to the axial direction of iron alloy wire 2. When the wire diameter is 2 mm or more and 5 mm or less, iron alloy wire 2 can be suitably used as elemental wire 30 included in core wire portion 50 of overhead power transmission line 5. The wire diameter may be 2.3 mm or more and 4.5 mm or less. It should be noted that in the case where iron alloy wire 2 is a cast material having been through a casting step under a below-described specific condition or is a processed material obtained by subjecting the cast material to plastic working such as rolling or wire drawing with a low degree of processing, the wire diameter of iron alloy wire 2 is more than 5 mm. With the casting step being performed under the specific condition, even when the wire diameter is large as described above, maximum diameter D of oxides 12 is less than 150 μm in iron alloy wire 2 composed of the cast material or the processed material.

[0120] When covering layer 22 is included, iron alloy wire 2 includes wire material 20 composed of iron alloy 1 of the embodiment and covering layer 22. Covering layer 22 covers the outer periphery of wire material 20. Covering layer 22 includes Al or Zn (zinc). That is, covering layer 22 is composed of aluminum, an aluminum alloy, zinc, or a zinc alloy. The thickness of covering layer 22 can be appropriately selected. The thickness is, for example, 0.5 μm or more and 500 μm or less. Fig. 2 shows covering layer 22 as being thick for convenience of explanation. It should be noted that in iron alloy wire 2 including covering layer 22, the wire diameter of iron alloy wire 2 is the diameter of wire material 20.

[0121] Fig. 2 illustrates overhead power transmission line 5 including core wire portion 50 and an electrical wire portion 52. Core wire portion 50 is used as a tensile strength material. Electrical wire portion 52 is a conductor that forms a power transmission path. Core wire portion 50 is constituted of iron alloy stranded wire 3 of the embodiment. Electrical wire portion 52 includes a plurality of elemental wires 55. The plurality of elemental wires 55 are stranded together on the outer periphery of core wire portion 50. Each of elemental wires 55 is a wire material composed of aluminum or an aluminum alloy. Such an overhead power transmission line 5 is a so-called aluminum conductor steel-reinforced cable (ACSR). In the case where iron alloy wire 2 included in core wire portion 50 includes covering layer 22, covering layer

22 serves to less likely proceed corrosion caused by contact between wire material 20 mainly composed of steel and elemental wire 55 mainly composed of aluminum, i.e., corrosion by contact between different types of metals.

(Main Functions and Effects)

[0122] Each of iron alloy 1 of the embodiment, iron alloy wire 2 of the embodiment, and iron alloy stranded wire 3 of the embodiment is excellent in high-temperature strength. Further, each of iron alloy 1 of the embodiment, iron alloy wire 2 of the embodiment, and iron alloy stranded wire 3 of the embodiment is excellent in twisting characteristic. These effects will be specifically described in the below-described test example.

[0123] Further, the linear expansion coefficient of iron alloy 1 of the embodiment is small. Therefore, when core wire portion 50 of overhead power transmission line 5 is composed of iron alloy wire 2 of the embodiment or iron alloy stranded wire 3 of the embodiment, an amount of sagging of overhead power transmission line 5 due to thermal expansion is reduced.

[Method of Manufacturing Iron Alloy]

[0124] Iron alloy 1 of the embodiment is manufactured by, for example, an iron alloy manufacturing method including the following steps.

[0125] (First Step) A cast material composed of an iron alloy having the above-described composition is manufactured.

[0126] In the casting step, an average cooling rate from 1450°C to 1400°C is 10°C/min or less.

[0127] (Second Step) The cast material is subjected to plastic working to manufacture a processed material having a predetermined shape.

[0128] (Third Step) The processed material is subjected to heat treatment.

[0129] The above-described iron alloy manufacturing method is based on the following knowledge.

[0130] Generally, an iron alloy includes oxides of elements included in the iron alloy. Examples of the oxides include silicon oxide (SiO), aluminum oxide (Al₂O₃), magnesium oxide (MgO), and the like. When maximum diameter D of the oxides is less than 150 μm, each of the oxides is less likely to become a starting point of cracking. In order for maximum diameter D of the oxides to become less than 150 μm, the cooling rate in the temperature range of change from the liquid phase to the solid phase, specifically, in the temperature range from 1450°C to 1400°C, is preferably made relatively low in the casting step. The following describes a relation between the cooling rate in the casting step and the sizes of the oxides with reference to the Stokes' law and Fig. 3.

$$(\text{Stokes' law}) V_s = \{D_p^2(\rho_p - \rho_f)g\} / 18\eta$$

V_s represents a floating velocity (cm/s) of a particle of an inclusion.

D_p represents a particle diameter (cm) of the inclusion.

ρ_p represents a density (g/cm³) of the inclusion.

ρ_f represents a density (g/cm³) of a fluid.

η represents a viscosity (g/(cm·s)) of the fluid.

g represents an acceleration of gravity (cm/s²).

[0131] Fig. 3 is a graph showing a relation between particle diameter D_p of the particle of the inclusion and floating velocity V_s of the particle. The horizontal axis of the graph represents particle diameter D_p . The vertical axis of the graph represents floating velocity V_s .

[0132] The inclusion here is an oxide. The fluid here is a molten steel, which is an molten alloy.

[0133] As shown in the Stokes' law, floating velocity V_s of the oxide is proportional to the square of particle diameter D_p of the oxide. That is, it can be said that as particle diameter D_p is larger, the oxide is more likely to float upward.

[0134] Cooling rate V_c during casting is set in the graph of Fig. 3. Here, the unit of the cooling rate is normally °C/s, which is different from the unit of the floating velocity, that is, cm/s. Therefore, cooling rate V_c here is assumed to correspond to a rate of progress of change from the liquid phase to the solid phase, rather than not a rate of temperature change. Particle diameter D_p of a particle having floating velocity V_s equal to cooling rate V_c is defined as D_{p0} . Floating velocity V_{s2} of a particle having a particle diameter D_{p2} larger than particle diameter D_{p0} is higher than cooling rate V_c . Therefore, it can be said that the molten steel becomes the solid phase after the particles having large particle diameters D_{p2} float upward in the liquid phase. As a result, no particles each having particle diameter D_{p2} remain in the cast material. On the other hand, floating velocity V_{s1} of each particle having particle diameter D_{p1} smaller than particle diameter D_{p0} is lower than cooling rate V_c . Therefore, it can be said that the molten steel becomes the solid phase before the particles

each having particle diameter D_{p1} float upward in the liquid phase. As a result, the particles each having particle diameter D_{p1} remain in the cast material. As cooling rate V_c is higher, particle diameter D_{p0} is larger. Therefore, it can be said that particle diameter D_{p1} of each of the particles remaining in the cast material is likely to be large.

[0135] Next, referring to Figs. 4A and 4B, floating states of the oxides in a mold for continuous casting will be described.

[0136] Each of Figs. 4A and 4B is a conceptual diagram of a periphery of the mold for continuous casting. A molten steel 100 is continuously supplied to mold 6 in a direction from the upper side to the lower side of the plane of sheet of each of Figs. 4A and 4B. Molten steel 100 comes into contact with mold 6 and is accordingly solidified. That is, molten steel 100 is changed from the liquid phase to the solid phase to become cast material 110. Cast material 110 is advanced toward the lower side in the plane of sheet of each of Figs. 4A and 4B. Such a continuous casting method in which molten steel 100 is supplied from above mold 6 and cast material 110 is pulled out from below mold 6 is a typical method as a continuous casting method for steel. In this continuous casting method, oxides 12 each having particle diameter D_{p2} larger than particle diameter D_{p0} float upward to the liquid phase region located on the upper side in mold 6 and remain in the liquid phase region. Oxides 12 each having particle diameter D_{p1} smaller than particle diameter D_{p0} is included in the solid phase region located on the lower side in mold 6. Oxides 12 included in the solid phase region are included in cast material 110 to be pulled out from below mold 6. As a result, cast material 110 includes substantially no oxides 12 each having large particle diameter D_{p2} and includes oxides 12 each having small particle diameter D_{p1} .

[0137] As shown in Fig. 4A, when cooling rate V_c is high, particle diameter D_{p0} is large as described above. Therefore, large oxides 12 are likely to be included in the solid phase region in mold 6. Further, when cooling rate V_c is high, the liquid phase is changed to the solid phase before large oxides 12 float upward. As a result, cast material 110 is likely to include large oxides 12.

[0138] As shown in Fig. 4B, when cooling rate V_c is low, particle diameter D_{p0} is small as described above. Therefore, the solid phase region in mold 6 is likely to include small oxides 12. Further, when cooling rate V_c is low, it takes a long time to change the liquid phase to the solid phase. Therefore, large oxides 12 are likely to float upward to the liquid phase region. As a result, cast material 110 is less likely to include large oxides 12.

[0139] In view of the above, in the above-described iron alloy manufacturing method, the sizes of the oxides are controlled by setting cooling rate V_c during casting to fall within the specific range. Here, generally, in casting, as the cooling rate is higher, the rate of manufacturing cast materials is higher, thereby facilitating mass production of cast materials. Further, conventionally, attention has not been paid to controlling the cooling rate in a specific temperature range. On the other hand, in the above-described iron alloy manufacturing method, during casting, the oxides are separated through flotation by setting the cooling rate to be relatively low in the temperature range in which the molten alloy is changed from 1450°C to 1400°C, i.e., the temperature range in which the molten alloy is changed from the liquid phase to the solid phase. As a result, a cast material including small oxides, rather than large oxides, is manufactured.

[0140] Hereinafter, each of the steps will be described.

(First Step)

[0141] In the first step, casting is performed. Examples of the casting method include a continuous casting method and an ingot casting method. In the casting step, an average cooling rate from 1450°C to 1400°C is adjusted to 10°C/min or less. When the average cooling rate is 10°C/min or less, maximum diameter D of the oxides included in the cast material becomes less than 150 μm . Further, in manufacturing steps after the casting, maximum diameter D of the oxides does not become large to be 150 μm or more. That is, when a cast material in which maximum diameter D of the oxides is less than 150 μm is used, maximum diameter D of the oxides is less than 150 μm also in a final product. When the average cooling rate is 8°C/min or less or 6°C/min or less, maximum diameter D is likely to become smaller.

[0142] As the continuous casting method, the above-described typical continuous casting method for steel can be used. Further, for the continuous casting method, a method other than the above-described method may be used, such as a twin-roll method or a twin-belt method, as long as the above-described average cooling rate can be achieved. By using the continuous casting method, maximum diameter D of the oxides is adjusted to fall within the above-described predetermined range, and long iron alloy 1 such as a wire material or a plate material is manufactured.

[0143] When the cross sectional area of the cast material is, for example, about 50,000 mm^2 or more and 500,000 mm^2 or less and the cross sectional shape of the cast material is a simple shape such as a circular shape or a quadrangular shape, the above-described adjustment of the cooling rate can be readily performed.

(Second Step)

[0144] In the second step, the cast material is subjected to one or more types of plastic working, thereby manufacturing a processed material. Multi-pass plastic working may be performed. Examples of the types of plastic working include rolling, forging, wire drawing, and the like. The plastic working may be hot plastic working or cold plastic working.

(Third Step)

[0145] In the third step, the processed material is subjected to heat treatment to precipitate carbides mainly, thereby attaining a strengthening effect due to precipitation hardening. For this purpose, the heat treatment includes aging treatment. The aging treatment is performed, for example, under the following conditions: a heat treatment temperature is selected from a range of 450°C or more and 750°C or less; and a heat treatment time is selected from a range of 3 hours or more and 15 hours or less. When the heat treatment temperature is 450°C or more and the heat treatment time is 3 hours or more, the carbides are precipitated. When the heat treatment temperature is 750°C or less and the heat treatment time is 15 hours or less, the carbides are less likely to become coarse. By the heat treatment, it can also be expected to attain an effect of removing strain having been introduced in the processed material so as to improve elongation.

[0146] The heat treatment may include solution treatment in addition to the aging treatment. The solution treatment is performed before the aging treatment. The solution treatment is performed, for example, under the following conditions: a heat treatment temperature is 1200°C; and a heat treatment time is 30 minutes. In the case where quenching is performed after performing hot plastic working in the second step, the solution treatment can be omitted.

[Method of Manufacturing Iron Alloy Wire]

[0147] Iron alloy wire 2 of the embodiment is manufactured by the above-described iron alloy manufacturing method. In this case, the plastic working in the second step may include wire drawing. Alternatively, as an example of the above-described iron alloy manufacturing method, the manufacturing method further includes a fourth step of performing wire drawing after the third step. The manufacturing method including the fourth step can be suitably used to manufacture an iron alloy wire 2 having a wire diameter of 5 mm or less.

[0148] As another example of the above-described iron alloy manufacturing method, the method includes: a fifth step of manufacturing a covered intermediate material by covering, with a metal member, the outer periphery of the wire drawing material manufactured in the fourth step; and a sixth step of further performing wire drawing onto the covered intermediate material. The manufacturing method including the fifth step and the sixth step can be suitably used to manufacture iron alloy wire 2 that includes covering layer 22. The covered intermediate material is manufactured, for example, as follows. Plating is applied to the outer periphery of the wire drawing material. The wire drawing material is inserted into a metal tube, and then the wire drawing material and the metal tube are fastened tightly. A metal material is clad on the outer periphery of the wire drawing material by conform extrusion.

[0149] A total area reduction ratio in the wire drawing process after the third step is, for example, 30% or more and 99% or less.

[Method of Manufacturing Iron Alloy Stranded wire]

[0150] Iron alloy stranded wire 3 of the embodiment is manufactured by stranding the plurality of iron alloy wires 2 together, for example.

[Test Example 1]

[0151] Structures and characteristics of steel wires of respective samples including elements shown in Tables 1 and 2 are shown in Tables 5 and 6. In each of the steel wires of the samples, the content of each element can be measured by various types of component analysis methods. In each of the steel wires of the samples, the remainder other than the components is Fe and an inevitable impurity. The content of oxygen in each of the steel wires of the samples is 0.003 mass% or less. The content of oxygen in the steel wire is measured by, for example, an inert gas fusion-infrared absorption method. A commercially available device can be used to measure the content of oxygen.

Components (Mass%)

[illegible]

[Table 2]

Sample No.	Components (Mass%)																						
	C	Si	Mn	Ni	Cr	V	Co	Ca	Ti	Al	Mg	Zr	Hf	Mo	Cu	Nb	Ta	W	B	V/C	Cr/C	V+Cr	(V+Cr)/C
101	0.3	0.3	1.2	39	1.5	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3	5.0	1.9	6.3
102	0.5	0.3	0.2	33	1.3	1.2	1.0	0.04	0.06	0.03	0.06	-	-	-	-	-	-	-	0.0021	2.4	2.6	2.5	5.0
103	0.08	1.1	1.5	40	1.2	1.7	1.0	0.03	0.02	0.01	-	-	-	-	-	-	-	-	-	21.3	15.0	2.9	36.3
104	0.2	1.0	0.42	37	1.1	2.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	12.5	5.5	3.6	18.0
105	0.3	0.5	0.3	38	0.2	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	3.7	0.7	1.3	4.3
106	0.3	0.5	0.3	38	0.2	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	3.7	0.7	1.3	4.3
107	0.3	0.5	0.2	40	0.8	0.8	0.2	-	-	-	-	-	-	-	-	-	-	-	-	2.7	2.7	1.6	5.3
201	0.3	0.5	0.3	38	0.2	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	3.7	0.7	1.3	4.3
202	0.2	1.0	0.2	36	0.3	1.8	-	-	-	0.05	-	-	-	-	-	-	-	-	-	9.0	1.5	2.1	10.5
203	0.3	0.8	0.75	34	1.5	1.5	2.0	-	-	-	-	-	-	-	-	-	-	-	-	5.0	5.0	3.0	10.0

[0152] Each of the steel wires of the samples other than samples No. 25 and No. 201 is manufactured by performing:

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the first step of performing continuous casting; the second step of performing hot plastic working and cold plastic working; the third step of performing heat treatment; and the fourth step of performing cold wire drawing. Tables 3 and 4 show manufacturing conditions.

[0153] In the manufacturing of each of the steel wires of samples No. 25 and No. 201, ingot casting, rather than the continuous casting, is used in the first step. In the manufacturing of each of the steel wires of samples No. 25 and No. 201, the second to fourth steps are performed in the same manner as in the other samples.

[Table 3]

Sample No.	Conditions		
	Cooling Rate (°C/min)	Heat Treatment (°C×5Hr)	Evaluation Wire Diameter (mm)
1	6	650	2.4
2	6	650	3.1
3	6	650	3.1
4	10	650	3.5
5	6	650	3.1
6	10	650	3.8
7	8	500	3.1
8	6	650	3.1
9	6	650	3.1
10	3	650	3.1
11	6	750	3.8
12	6	650	3.1
13	6	650	3.1
14	6	650	3.1
15	6	650	3.1
16	6	650	3.1
17	6	600	3.1
18	6	600	3.1
19	6	650	3.1
20	6	650	3.1
21	6	650	3.1
22	10	650	3.1
23	2	650	3.1
24	8	650	3.1
25	8	650	3.1

[Table 4]

Sample No.	Conditions		
	Cooling Rate (°C/min)	Heat Treatment (°C×5Hr)	Evaluation Wire Diameter (mm)
101	6	650	3.1
102	10	650	3.1
103	6	650	3.1

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(continued)

Sample No.	Conditions		
	Cooling Rate (°C/min)	Heat Treatment (°C×5Hr)	Evaluation Wire Diameter (mm)
104	3	650	3.1
105	6	350°C×2Hr	3.1
106	6	650°C×20Hr	3.1
107	6	650	6.8
201	15	650	3.1
202	20	650	3.1
203	20	650	3.1

[0154] The cooling rate (°C/min) shown in each of Tables 3 and 4 is an average cooling rate in a range of 1450°C to 1400°C in the continuous casting step or the ingot casting step. Here, the continuous casting method is a method in which molten steel is continuously supplied from above a mold and a cast material is pulled out from below the mold. The ingot casting is a method in which a predetermined amount of molten steel is supplied to a mold having predetermined shape and size and the molten steel is cooled to manufacture a cast material. In each of the continuous casting method and the ingot casting method, the cooling rate can be changed by adjusting a type of a cooling medium, a temperature of the cooling medium, a casting rate for the cast material, and the like.

[0155] The cooling rate in each of samples No. 201 to No. 203 is 15°C/min or more.

[0156] In the second step, the continuous cast material or ingot cast material having a cross sectional area of about 200,000 mm² is subjected to hot plastic working and cold plastic working to manufacture a processed material having a diameter of 8 mm and a circular cross sectional shape.

[0157] In the third step, a heat-treated material is manufactured by performing heat treatment onto the above-described processed material under a heat treatment condition shown in Tables 3 and 4 at a temperature (°C) shown in Tables 3 and 4. A heat treatment time for each of the samples other than samples No. 105 and No. 106 is 5 hours. A heat treatment time for sample No. 105 is 2 hours. A heat treatment time for sample No. 106 is 20 hours.

[0158] In the fourth step, cold wire drawing is performed onto the heat-treated material until a wire drawing material having an evaluation wire diameter (mm) shown in Tables 3 and 4 is obtained, thereby manufacturing a steel wire. By the above steps, each of the steel wires of the samples is manufactured. The evaluation wire diameter in each of the samples other than the following samples is 3.1 mm. The evaluation wire diameter in sample No. 1 is 2.4 mm. The evaluation wire diameter in sample No. 4 is 3.5 mm. The evaluation wire diameters in samples No. 6 and No. 11 are 3.8 mm. The evaluation wire diameter in sample No. 107 is 6.8 mm.

(Structure Observation)

[0159] Each of the steel wires of the samples is cut along a plane parallel to the axial direction of each steel wire to obtain a longitudinal cross section, and maximum diameter D and the number density of the oxides are evaluated by using a SEM observation image of the longitudinal cross section. An observation magnification is 200x.

[0160] Three or more longitudinal cross sections are taken from each of the steel wires of the samples. From each longitudinal cross section, a first observation region of 2 mm × 20 mm is taken. Further, a second observation region of 2 mm × 3 mm is taken from each first observation region. As described above, the diameter of each oxide included in the first observation region is calculated. By using oxides each having a diameter of 1 μm or more, maximum diameter D of the oxides in each first observation region is calculated. In each of the steel wires of the samples, the average value of three or more maximum diameters D calculated for three or more first observation regions is defined as maximum diameter D of the oxides in the steel wire of the sample. Further, the number density of the oxides in each second observation region is calculated by using the oxides each having a diameter of 1 μm or more. In each of the steel wires of the samples, the average value of three or more number densities calculated for three or more second observation regions is defined as the number density of the oxides in the steel wire of the sample.

(Mechanical Characteristics at Room Temperature)

[0161] Each of the steel wires of the samples is subjected to a tensile test at room temperature in accordance with JIS Z 2241:2011 so as to evaluate tensile strength σ_{RT} , work-hardening coefficient, and breaking elongation. Here, the

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work-hardening coefficient is defined as a value obtained by dividing 0.2% proof stress of a test piece sampled from each of the steel wires of the samples by tensile strength of the test piece.

(Mechanical Characteristics at High Temperature)

[0162] A high-temperature strength ratio of each of the steel wires of the samples is evaluated. The high-temperature strength ratio is a ratio σ_{300}/σ_{RT} of tensile strength σ_{300} at 300°C to tensile strength σ_{RT} at room temperature. Tensile strength σ_{300} at 300°C is found by performing a tensile test as described above at 300°C.

(Twisting Characteristic)

[0163] Each of the steel wires of the samples is subjected to a twisting test at room temperature using a commercially available twisting test machine so as to evaluate a twisting characteristic. Ten test pieces are taken from each of the steel wires of the samples to each have a length (100D) that is 100 times as large as the evaluation wire diameter shown in Tables 3 and 4. For example, in sample No. 1, each test piece is a wire material having a length of $2.4 \text{ mm} \times 100 = 240 \text{ mm}$. One end portion of both end portions of each test piece is fixed and the other end portion is connected to the twisting test machine. That is, one end portion of each test piece is fixed. Each test piece having one end fixed is twisted. The twisting is performed by the twisting test machine at a rotation speed of 60 rpm. The number of times of twisting until breakage of each test piece is measured. In each sample, the numbers of times of twisting the ten test pieces are averaged. This average value is defined as the average number of times of twisting in the sample. The average number of times of twisting each of the steel wire of sample No. 24 and the steel wire of sample No. 201 is evaluated also in the case where the rotation speed is set to 30 rpm.

(Linear Expansion Coefficient)

[0164] The linear expansion coefficient (ppm/°C) of each of the steel wires of the samples is evaluated. Here, test pieces are taken from each of the steel wires of the samples, and a length L_{30} of each test piece at 30°C and a length L_{230} of each test piece at 230°C are measured. Calculation is performed as follows: $(\text{length } L_{230} \text{ at } 230^\circ\text{C} - \text{length } L_{30} \text{ at } 30^\circ\text{C}) / (230^\circ\text{C} - 30^\circ\text{C}) / (\text{length } L_{30} \text{ at } 30^\circ\text{C})$. The calculated value is defined as an average linear expansion coefficient at 30°C to 230°C. Each of the linear expansion coefficients shown in Tables 5 and 6 is the average linear expansion coefficient.

[Table 5]

Sample No.	Characteristics						Oxides	
	Tensile Strength σ_{RT} (MPa)	Work-Hardening Coefficient	Breaking Elongation (%)	High-Temperature Strength Ratio (σ_{300}/σ_{RT})	Twisting Characteristic (100D)	Linear Expansion Coefficient (ppm/°C)	Maximum Diameter (μm)	Number Density
1	1329	0.97	2.3	0.87	86	3.9	87	142
2	1323	0.95	2.5	0.87	96	3.7	85	132
3	1368	0.98	2.6	0.87	101	2.4	81	81
4	1413	0.98	2.3	0.84	93	3.2	110	55
5	1412	0.90	2.8	0.89	106	1.2	90	23
6	1488	0.98	2.0	0.82	85	3.8	145	26
7	1362	0.85	3.0	0.85	59	1.2	98	98
8	1383	0.97	2.1	0.89	84	3.2	95	79
9	1376	0.98	1.9	0.91	78	2.7	72	60
10	1394	0.98	0.9	0.97	40	3.9	30	40
11	1255	0.96	0.9	0.95	40	4.0	91	67
12	1445	0.98	1.9	0.93	78	2.9	87	38
13	1439	0.97	1.9	0.94	77	2.9	85	39
14	1439	0.93	2.3	0.88	91	2.0	99	40
15	1476	0.98	1.2	0.93	53	3.2	90	38
16	1487	0.98	1.1	0.93	48	3.4	80	32
17	1513	0.98	0.9	0.94	33	3.6	95	42
18	1515	0.98	0.8	0.92	37	3.5	65	32
19	1363	0.98	2.5	0.86	99	3.9	77	77
20	1397	0.98	2.5	0.89	100	1.9	88	30
21	1415	0.97	1.4	0.94	60	3.2	90	37
22	1398	0.98	2.3	0.90	90	22	105	52
23	1393	0.98	1.0	0.97	46	40	20	16

(continued)

Sample No.	Characteristics						Oxides	
	Tensile Strength σ_{RT} (MPa)	Work-Hardening Coefficient	Breaking Elongation (%)	High-Temperature Strength Ratio (σ_{300}/σ_{RT})	Twisting Characteristic (100D)	Linear Expansion Coefficient (ppm/°C)	Maximum Diameter (μm)	Number Density
24	1416	0.98	2.3	0.83	74	2.7	98	44
25	1404	0.98	2.1	0.81	53	2.7	146	50

[Table 6]

Sample No.	Characteristics						Oxides	
	Tensile Strength σ_{RT} (MPa)	Work-Hardening Coefficient	Breaking Elongation (%)	High-Temperature Strength Ratio (σ_{300}/σ_{RT})	Twisting Characteristic (100D)	Linear Expansion Coefficient (ppm/°C)	Maximum Diameter (μm)	Number Density
101	1469	0.98	0.7	0.95	25	4.1	85	22
102	1377	0.98	0.5	0.95	28	4.8	39	150
103	900	0.98	1.5	0.94	51	3.8	75	91
104	1398	0.98	1.9	0.94	77	4.3	44	39
105	1666	0.94	0.2	0.80	5	2.9	85	37
106	1325	0.96	0.6	0.85	20	2.7	105	41
107	945	0.95	4.5	0.82	129	2.9	86	32
201	1398	0.98	2.0	0.78	27	2.8	175	92
202	1301	0.95	2.1	0.77	48	2.4	240	235
203	1389	0.98	0.8	0.79	11	3.9	259	7

[0165] Hereinafter, each of the steel wires of samples No. 1 to No. 25 each having the specific composition described in the above-described section "(Composition)" will be referred to as "steel wire of the specific sample group".

[0166] As shown in Tables 5 and 6, it is understood that each of the steel wires of the specific sample group has an excellent high-temperature strength. Quantitatively, the high-temperature strength ratio of each of the steel wires of the specific sample group is 0.8 or more, and is higher than the high-temperature strength ratio of each of the steel wires of samples No. 201 to No. 203. Many samples of the specific sample group each have a high-temperature strength ratio of 0.82 or more. One reason for such a result is considered as follows: in each of the steel wires of the specific sample group, maximum diameter D of the oxides is small to be less than 150 μm , with the result that each of the oxides is less likely to be a starting point of cracking at high temperature. In each of many samples of the specific sample group, maximum diameter D of the oxides is 145 μm or less. On the other hand, in the steel wires of samples No. 201 to No. 203, maximum diameter D of the oxides is 150 μm or more, here, is 170 μm or more. In each of the steel wires of samples No. 202 and No. 203, maximum diameter D of the oxides is 240 μm or more and is much larger. Since maximum diameter D is thus large, the high-temperature strength of the steel wire of sample No. 201 is lower than the high-temperature strength of each of samples No. 204 and No. 205 having the same composition as the composition of sample No. 201. In the steel wire of sample No. 202, the high-temperature strength is significantly lower than the high-temperature strength of sample No. 3 having the same composition as the composition of sample No. 202. In the steel wire of sample No. 203, the high-temperature strength is significantly lower than the high-temperature strength of sample No. 23 having the same composition as the composition of sample No. 203. Here, the high-temperature strength of the steel wire of sample No. 202 is the lowest among the samples.

[0167] Further, it is understood that each of the steel wires of the specific sample group is excellent in twisting characteristic. Quantitatively, in each of the steel wires of the specific sample group, the average number of times of twisting in the twisting characteristic is 30 or more, and is more than the average number of times of twisting in each of the steel wires of samples No. 201 and No. 203. For example, the steel wires of samples No. 204 and No. 205 are compared with the steel wire of sample No. 201, all of which have the same composition. Moreover, the steel wire of sample No. 203 is compared with the steel wire of sample No. 203, both of which have the same composition. Further, when the steel wires of samples No. 3 and No. 202 both having the same composition are compared with each other, the average number of times of twisting in the twisting characteristic in the steel wire of sample No. 3 is larger than that of sample No. 202.

[0168] In view of the above, it can be said that each of the steel wires of the specific sample group has excellent high-temperature strength and twisting characteristic. One reason for such a result is considered as follows: in each of the steel wires of the specific sample group, maximum diameter D of the oxides is small to be less than 150 μm , with the result that each of the oxides is less likely to become a starting point of cracking both at the high temperature and at the time of twisting. Also, in the steel wire of the specific sample group, the high-temperature strength ratio and the average number of times of twisting are likely to be high presumably due to the following reason: since the number density of the oxides is small to be 500 or less, here, 150 or less, propagation of cracking by the oxides is less likely to occur.

[0169] It should be noted that the average number of times of twisting in the twisting characteristic at a rotation speed of 30 rpm is 135 in the case of the steel wire of sample No. 204 and is 65 in the case of the steel wire of sample No. 201. In view of this, it can be said that even when the rotation speed during the twisting becomes large, the steel wire of sample No. 204 is less likely to be broken as compared with the steel wire of sample No. 201. For example, when manufacturing a stranded wire using a steel wire of the specific sample group as an elementary wire, the rotation speed during stranding can be made fast. In view of this point, it is expected that each of the steel wires of the specific sample group contribute to mass production of stranded wires.

[0170] Regarding maximum diameter D of the oxides, as shown in Tables 3 and 4, it is understood that as the cooling rate in the above-described specific temperature range in the casting step is lower, maximum diameter D of the oxides tends to be smaller. Here, it can be said that when the cooling rate is less than 15°C/min, particularly, 10°C/min or less, maximum diameter D of the oxides becomes less than 150 μm . In each of the steel wires of samples No. 202 and No. 203 in each of which the cooling rate is 20°C/min, maximum diameter D of the oxides is 240 μm or more, which is very large. In view of these, it can be said that in order to attain a small maximum diameter D of the oxides, the cooling rate in the specific temperature range is preferably 10°C/min or less in the casting step.

[0171] Further, the following matters are understandable with regard to the specific sample group.

(1) Tensile strength σ_{RT} at room temperature is 1250 MPa or more. In each of many samples, tensile strength σ_{RT} is 1300 MPa or more. In each of a plurality of samples, tensile strength σ_{RT} is 1350 MPa or more or 1400 MPa or more. It is considered that also due to the high strength at room temperature, the specific sample group is likely to attain a high tensile strength even at high temperature.

(2) The breaking elongation at room temperature is 0.8% or more. In each of many samples, the breaking elongation is 1.0% or more. It is considered that also due to the high elongation at room temperature, the specific sample group attains an excellent twisting characteristic.

(3) The work-hardening coefficient at room temperature is 0.7 or more, here, 0.85 or more. The work-hardening coefficient of each of many samples is 0.9 or more. Since the work-hardening coefficient is thus high, the specific sample group attains an excellent impact resistance.

(4) The average linear expansion coefficient at 30°C to 230°C is 4 ppm/°C or less. Since the linear expansion coefficient is thus small in the range from the room temperature to the high temperature such as 200°C or more, an amount of thermal expansion is small in the specific sample group even at a high temperature.

[0172] In addition, the following matters are understandable from this test.

[0173] The steel wires of samples No. 102 and No. 103 do not have the above-described specific composition.

[0174] The steel wire of sample No. 102 including large amounts of C and the elements of the second group has a lower elongation, has an inferior twisting characteristic, and has a large average linear expansion coefficient as compared with the steel wires of the specific sample group.

[0175] The steel wire of sample No. 103 having a small amount of C has a low strength.

[0176] The steel wire of sample No. 101 has a lower elongation, has an inferior twisting characteristic, and has a large average linear expansion coefficient as compared with the steel wires of the specific sample group. One reason for this is considered as follows: since ratio V/C is small to be less than 2 in the steel wire of sample No. 101, precipitation of carbides including V is insufficient. Also, the steel wire of sample No. 101 has a strength lower than that of sample No. 16 having a composition relatively close to that of sample No. 101.

[0177] The steel wire of sample No. 104 has an average linear expansion coefficient larger than that of each of the steel wires of the specific sample group. One reason for this is considered as follows: in the steel wire of sample No. 104, ratio V/C is large to be more than 10 and ratio ((V+Cr)/C) is large to be more than 15.

[0178] Each of the steel wires of samples No. 105 and No. 106 has a low elongation and has an inferior twisting characteristic as compared with each of the steel wires of the specific sample group. For example, in each of the steel wires of samples No. 105 and No. 106, the twisting characteristic is significantly decreased as compared with sample No. 24 having the same composition as that of each of samples No. 105 and No. 106. One reason for this with regard to the steel wire of sample No. 105 is considered as follows: since the heat treatment temperature is low and the heat treatment time is short in the heat treatment step, carbides are not sufficiently precipitated. A reason therefor with regard to the steel wire of sample No. 106 is considered as follows: since the heat treatment time is long in the heat treatment step, carbides become coarse.

[0179] The steel wire of sample No. 107 is inferior in strength to each of the steel wires of the specific sample group. One reason for this is considered as follows: since the total area reduction ratio is small in the cold drawing step in the steel wire of sample No. 107, the strengthening effect due to work hardening is insufficient.

[0180] In view of the above description, it has been proved that the high-temperature strength is excellent in the iron alloy which has the above-described specific composition and in which maximum diameter D of the oxides is less than 150 μm. It has been also proved that this iron alloy has an excellent twisting characteristic. Moreover, it has been proved that this iron alloy is excellent in strength and elongation at room temperature, and has a small linear expansion coefficient in the range of 30°C to 230°C. Further, it has been proved that such an iron alloy can be manufactured by adjusting the cooling rate in the above-described specific temperature range to fall within the above-described specific range in the casting step. Furthermore, it has been proved that even when the content of oxygen is controlled to fall within the specific range, maximum diameter D of the oxides differs depending on a difference in manufacturing conditions such as the cooling rate.

[0181] The present invention is not limited to these examples, is defined by claims, and is intended to include any modification within the scope and meaning equivalent to the claims. For example, the compositions and manufacturing conditions of the iron alloys shown in Test Example 1 can be changed.

REFERENCE SIGNS LIST

[0182] 1: iron alloy; 10: matrix; 12: oxide; 2: iron alloy wire; 20: wire material; 22: covering layer; 3: iron alloy stranded wire; 30: elemental wire; 5: overhead power transmission line; 50: core wire portion; 52: electrical wire portion; 55: elemental wire; 6: mold; 100: molten steel; 110: cast material.

Claims

1. An iron alloy comprising:

a composition including, in mass%,

0.10% or more and 0.4% or less of C,
 0.2% or more and 2.0% or less of Si,
 0.05% or more and 2.0% or less of Mn,
 25% or more and 42% or less of Ni,
 0.1% or more and 3.0% or less of Cr,
 0.2% or more and 3.0% or less of V,
 0% or more and 0.1% or less of a total of one or more elements selected from a group consisting of Ca,
 Ti, Al, and Mg,
 0% or more and 0.1% or less of a total of one or more elements selected from a group consisting of Zr, Hf,
 Mo, Cu, Nb, Ta, W, and B, and
 0% or more and 5% or less of Co, a remainder of the composition consisting of Fe and an inevitable impurity;
 and

a structure having a matrix in which oxides are dispersed, wherein
 in a cross section of the iron alloy, a maximum diameter of the oxides included in a region of 2 mm × 20 mm
 is less than 150 μm.

2. The iron alloy according to claim 1, wherein in the cross section, the number of the oxides included in a region of 2 mm × 3 mm is 500 or less.
3. The iron alloy according to claim 1 or 2, wherein a content of oxygen in the composition is 0.003 mass% or less.
4. The iron alloy according to any one of claims 1 to 3, wherein a ratio σ_{300}/σ_{RT} of a tensile strength σ_{300} at 300°C to a tensile strength σ_{RT} at room temperature is 0.8 or more.
5. The iron alloy according to any one of claims 1 to 4, wherein ten test pieces each having a shape of line and each having a length that is 100 times as large as a diameter of the test piece are taken from the iron alloy, and an average value of the respective numbers of times of twisting, at a rotation speed of 60 rpm, the test pieces with one end of each of the test pieces being fixed until breakage of the test pieces is 30 or more.
6. The iron alloy according to any one of claims 1 to 5, wherein a tensile strength σ_{RT} of the iron alloy at room temperature is 1250 MPa or more.
7. The iron alloy according to any one of claims 1 to 6, wherein an average linear expansion coefficient of the iron alloy at 30°C to 230°C is 4 ppm/°C or less.
8. The iron alloy according to any one of claims 1 to 7, wherein a breaking elongation of the iron alloy at room temperature is 0.8% or more.
9. The iron alloy according to any one of claims 1 to 8, wherein a work-hardening coefficient of the iron alloy at room temperature is 0.7 or more.
10. An iron alloy wire composed of the iron alloy according to any one of claims 1 to 9.
11. The iron alloy wire according to claim 10, comprising a wire material composed of the iron alloy, and a covering layer that covers an outer periphery of the wire material, wherein the covering layer includes Al or Zn.
12. The iron alloy wire according to claim 10 or 11, wherein a wire diameter of the iron alloy wire is 2 mm or more and 5 mm or less.
13. An iron alloy stranded wire comprising a plurality of elemental wires stranded together, wherein at least one elemental wire of the plurality of elemental wires is the iron alloy wire according to any one of claims 10 to 12.

FIG.1

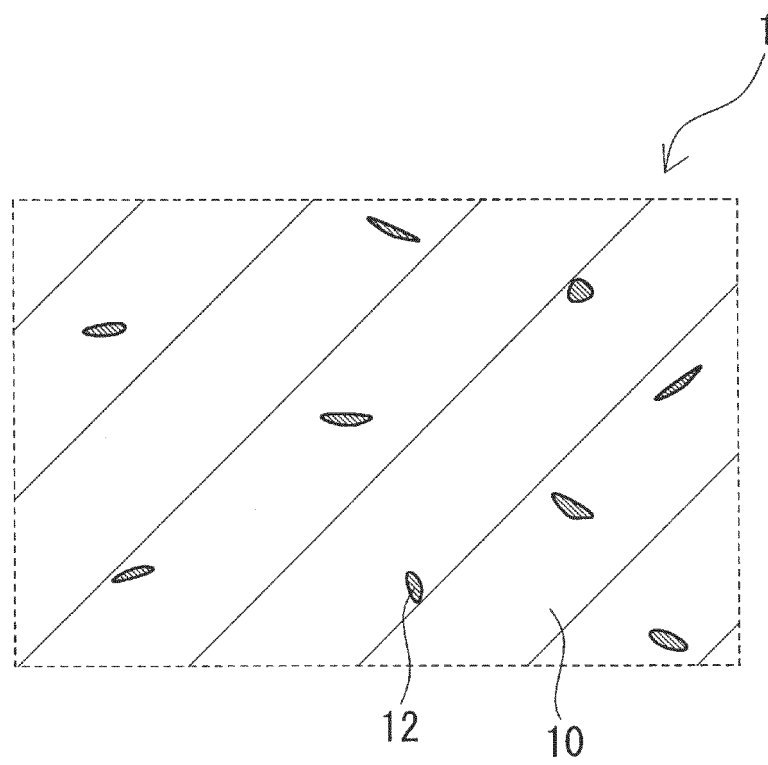


FIG.2

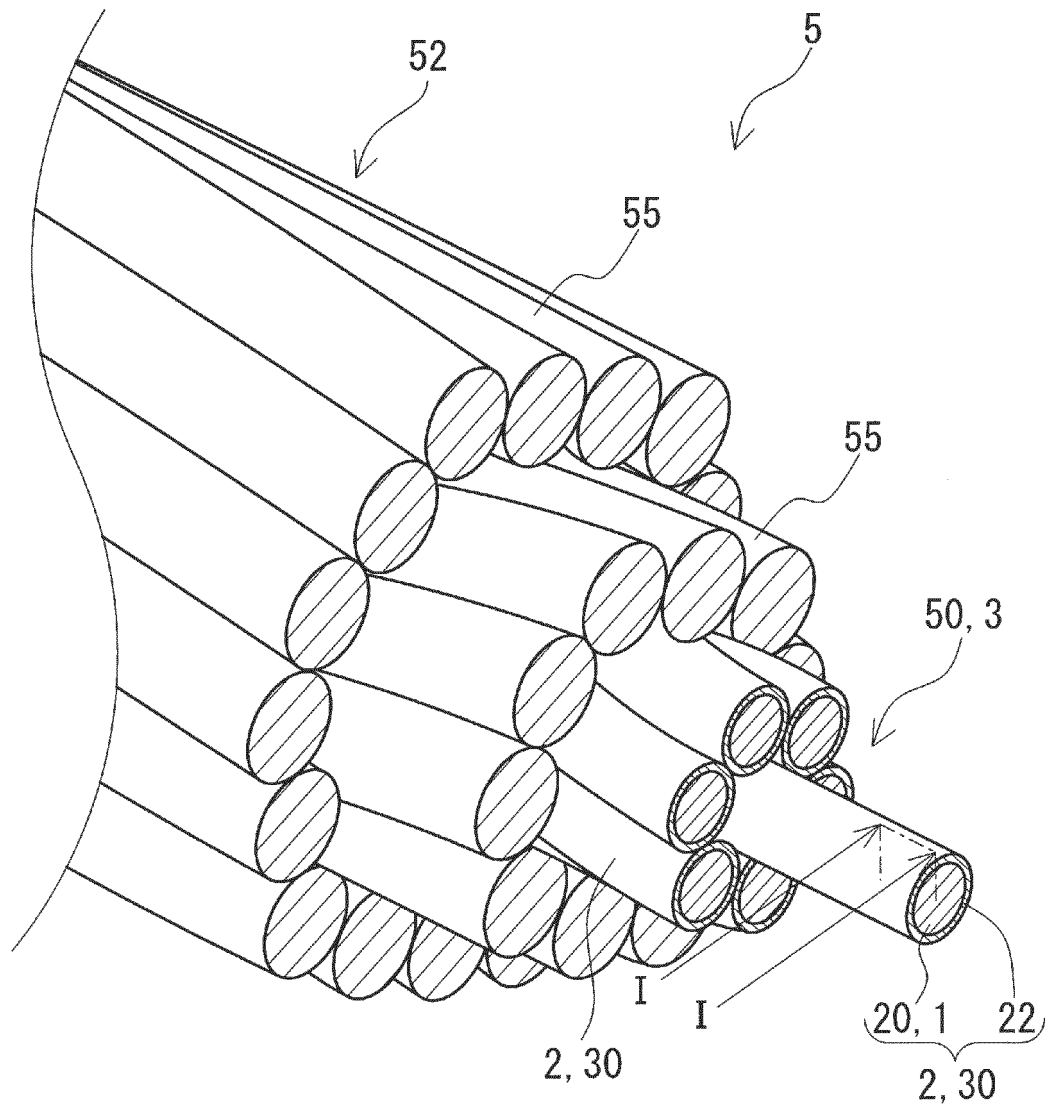


FIG.3

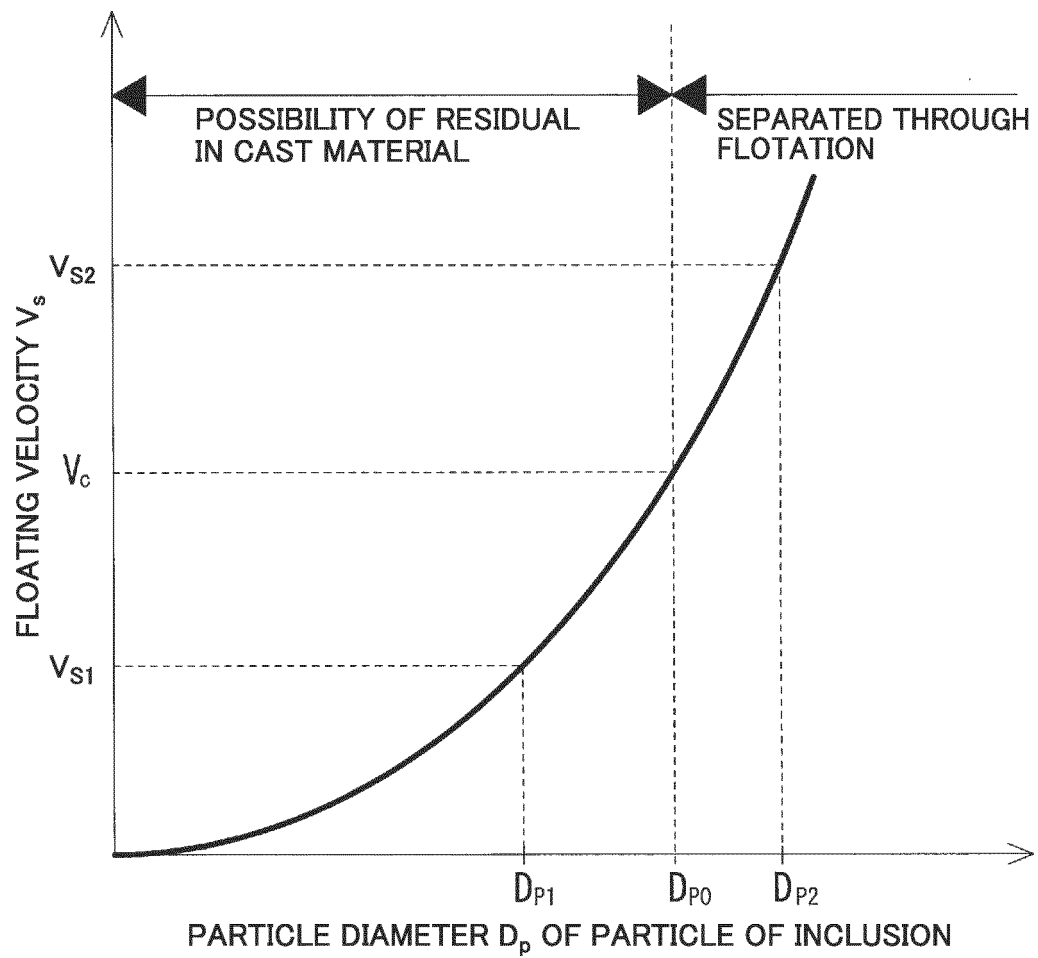


FIG.4A

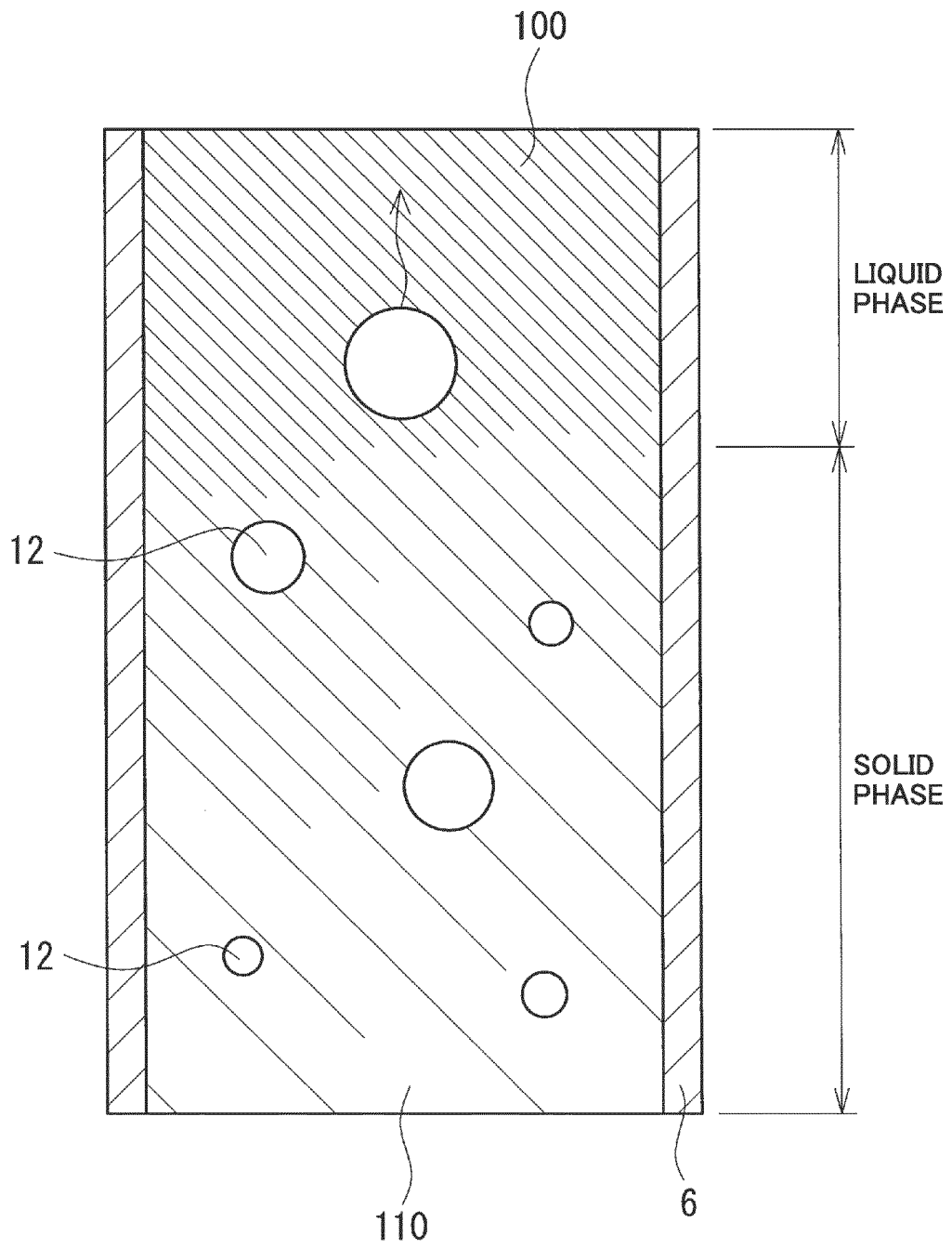
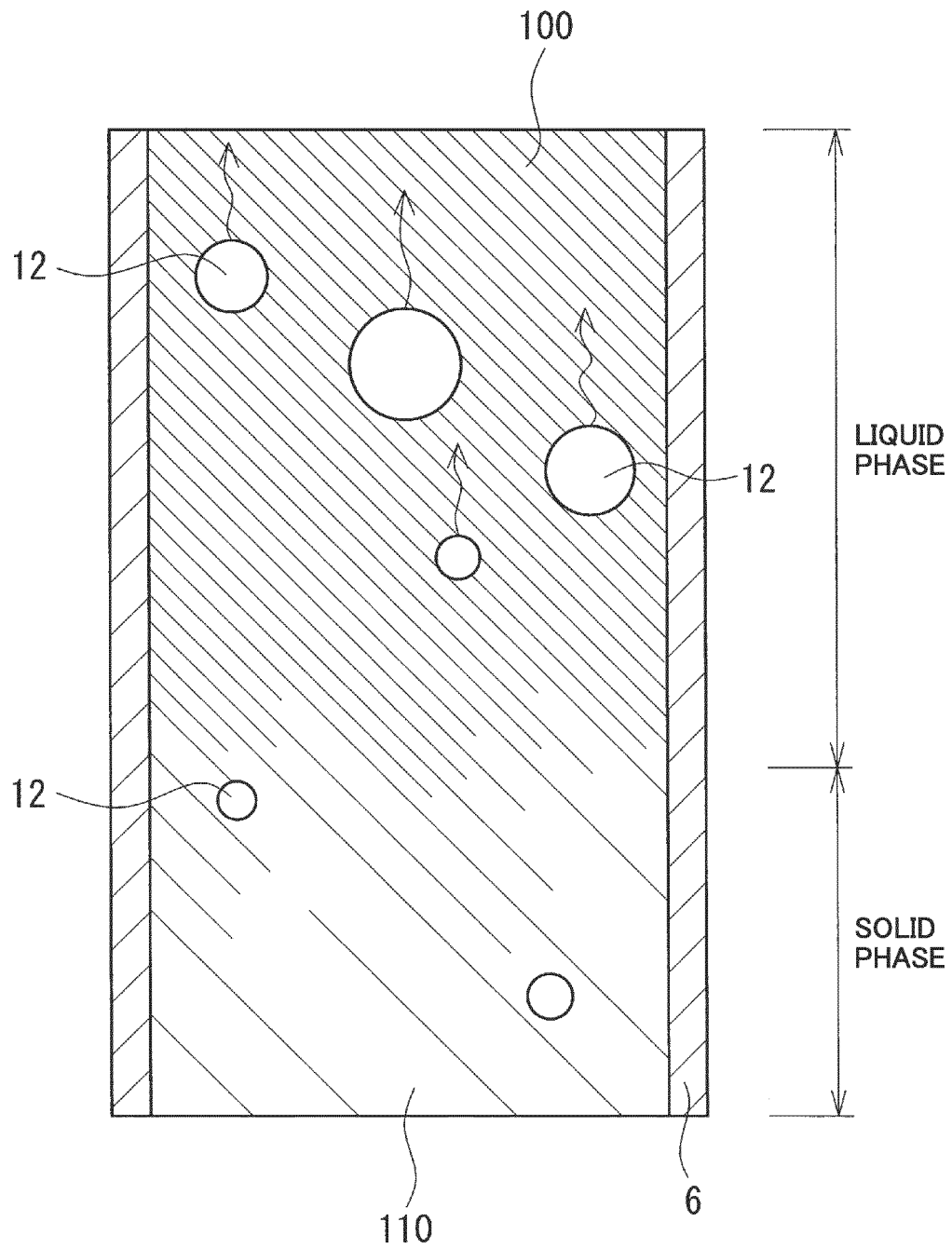


FIG.4B



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/021008

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. B22D27/04(2006.01)i, C21D8/06(2006.01)i, C22C38/00(2006.01)i,
C22C38/58(2006.01)i, B22D11/00(2006.01)i, B22D11/22(2006.01)i
FI: C22C38/00 302R, C22C38/58, C21D8/06 B, B22D11/00 A, B22D11/22 B, B22D27/04 G

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)

Int. Cl. B22D27/04, C21D8/06, C22C38/00-C22C38/60, B22D11/00, B22D11/22

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	JP 7-228947 A (SANYO SPECIAL STEEL CO., LTD.) 29	1-3, 6, 10
Y	August 1995 (1995-08-29), claims, paragraphs	1-3, 6-8, 10-
A	[0001]-[0005], [0013], [0017], [0019], table 1	13
		4-5, 9
Y	JP 2010-24489 A (SUMITOMO ELECTRIC INDUSTRIES,	1-3, 6-7, 10-
A	LTD.) 04 February 2010 (2010-02-04), claims,	13
	paragraphs [0001]-[0007], [0030]-[0034], [0036]-	4-5, 8-9
	[0039], tables 1, 2	
Y	JP 2002-256395 A (SANYO SPECIAL STEEL CO., LTD.)	1-3, 6, 8, 10-
A	11 September 2002 (2002-09-11), claims, paragraphs	13
	[0001], [0002], [0026], [0027], table 1	4-5, 7, 9



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search
12.08.2021Date of mailing of the international search report
24.08.2021

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/021008

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

10

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 9-316603 A (SUMITOMO ELECTRIC INDUSTRIES, LTD.) 09 December 1997 (1997-12-09), entire text, all drawings	1-13
A	JP 7-211143 A (HITACHI CABLE LTD.) 11 August 1995 (1995-08-11), entire text, all drawings	1-13
A	WO 2018/193810 A1 (SANYO SPECIAL STEEL CO., LTD.) 25 October 2018 (2018-10-25), entire text, all drawings	1-13

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/JP2021/021008

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JP 7-228947 A	29.08.1995	(Family: none)	
JP 2010-24489 A	04.02.2010	(Family: none)	
JP 2002-256395 A	11.09.2002	DE 10208855 A1 claims, paragraphs [0001], [0002], [0033]-[0035], table 1 KR 10-2002-0070815 A KR 10-2005-0087773 A KR 10-2007-0009960 A KR 10-2007-0057747 A	
JP 9-316603 A	09.12.1997	(Family: none)	
JP 7-211143 A	11.08.1995	(Family: none)	
WO 2018/193810 A1	25.10.2018	CN 110546292 A entire text, all drawings KR 10-2020-0003794 A	

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- JP 2002256395 A [0003]
- WO 2018193810 A [0003]