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(54) COLD-ROLLED STEEL SHEET AND METHOD FOR PRODUCING COLD-ROLLED STEEL SHEET

(57) A cold-rolled steel sheet having high strength and good hole expandability is provided. A cold-rolled steel sheet has a chemical composition of, in mass %: 0.10 to 0.30 % C; up to 2.50 % Si; 0.50 to 3.50 % Mn; up to 0.100 % P; up to 0.020 % S; 0.010 to 0.100 % Al; up to 0.0100 % N; 0 to 0.100 % Ti; 0 to 0.100 % Nb; 0 to 0.50 % V; 0 to 0.50 % Mo; 0 to 0.50 % W; 0 to 0.0050 % B; 0 to 0.0100 % Ca; 0 to 0.0100 % Mg; 0 to 0.0100 % REM; and balance Fe and impurities, the microstructure containing tempered martensite and bainite in not less than 85 volume % in total, the structure(s) other than the tempered martensite, bainite and ferrite being present in not more than 5 volume %, the regions where the Mn concentration in the microstructure is not lower than 8.0 mass % being present in 0.05 to 1.5 area %.

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Description

TECHNICAL FIELD

[0001] The present invention relates to a cold-rolled steel sheet and a method of manufacturing a cold-rolled steel sheet.

BACKGROUND ART

[0002] A steel sheet used in automobile parts, for example, is required to have high strength and also good formability.

[0003] WO 2018/030502 A1 discloses a high-strength steel sheet having a tensile strength not lower than 980 MPa and good formability. This steel sheet contains predetermined amounts of Cr and Mo, where the average grain size of the ferrite phase is not larger than 1.5 pm, the area ratio of the ferrite phase is not lower than 2 % and not higher than 15 %, the area ratio of the tempered martensite phase is not lower than 75 % and not higher than 96 %, and, per unit area, the sum of the interface length between the untempered martensite phase and the ferrite phase and the interface length between the untempered martensite phase and the tempered martensite phase is not smaller than $6.3 \times 10^{8}\ \mu m/m^{2}$ and not larger than $5.0 \times 10^{11}\ \mu m/m^{2}$.

[0004] JP 2016-194139 A discloses a high-strength cold-rolled steel sheet with a tensile strength not lower than 980 MPa and good formability as evaluated based on ductility and flange properties, as well as good collisional properties. This steel sheet has a microstructure, as seen at 1/4 of the sheet thickness, in which the area ratio of ferrite to the total microstructure is higher than 10 % and not higher than 65 % when the microstructure is observed by scanning electron microscopy, and the balance is a hard phase containing quenched martensite and retained austenite and composed of at least one selected from the group consisting of bainitic ferrite, bainite and tempered martensite.

[0005] JP 2015-193897 A discloses a high-strength cold-rolled steel sheet with a tensile strength not lower than 980 MPa and good ductility and bendability. This steel sheet has a microstructure, as seen at 1/4 of the sheet thickness of the steel sheet, in which the area ratio of ferrite to the total microstructure is not lower than 5 % and lower than 50 % when observed by scanning electron microscopy, and the balance is a hard phase. Furthermore, when analyzed by an electron-beam microprobe analyzer, the regions with an Mn concentration not lower than 1.2 times the Mn concentration in the steel sheet are present in 5 area % or more and, when for a 2 pm square section the fraction of regions with an Mn concentration not lower than 1.2 times the Mn concentration in the steel sheet is measured, the standard deviation of the measurements for 100 sections is not lower than 4.0 %.

[0006] WO 2008/042982 A2 describes a method of processing an iron-based alloy, including the steps of: raising the temperature of an iron-based alloy having a first microstructure capable of transforming to a second microstructure to the austenite transformation temperature; rapidly heating the iron-based alloy to a temperature higher than the austenite transformation temperature, and immediately quenching at least a portion of the iron-based alloy using quenching equipment adjacent to the heating equipment.

PRIOR ART DOCUMENTS

PATENT DOCUMENTS

[0007]

Patent Document 1: WO 2018/030502 A1
Patent Document 2: JP 2016-194139 A
Patent Document 3: JP 2015-193897 A
Patent Document 4: WO 2008/042982 A2

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0008] A problem to be solved by the present invention is to provide a cold-rolled steel sheet having high strength and good formability, and, more specifically, to provide a cold-rolled steel sheet having high strength and good hole expandability.

MEANS FOR SOLVING THE PROBLEMS

[0009] A cold-rolled steel sheet according to one embodiment of the present invention has a chemical composition of, in mass %: 0.10 to 0.30 % C; up to 2.50 % Si; 0.50 to 3.50 % Mn; up to 0.100 % P; up to 0.020 % S; 0.010 to 0.100 % Al; up to 0.0100 % N; 0 to 0.100 % Ti; 0 to 0.100 % Nb; 0 to 0.50 % V; 0 to 0.50 % Mo; 0 to 0.50 % W; 0 to 0.0050 % B; 0 to 0.0100 % Ca; 0 to 0.0100 % Mg; 0 to 0.0100 % REM; and balance Fe and impurities, a microstructure containing tempered martensite and bainite in not less than 85 volume % in total, a structure other than the tempered martensite, bainite and ferrite being present in not more than 5 volume %, regions where an Mn concentration in the microstructure is not lower than 8.0 mass % being present in 0.05 to 1.5 area %.

[0010] A method of manufacturing a cold-rolled steel sheet according to one embodiment of the present invention is a method of manufacturing the above-described cold-rolled steel sheet, including: performing a heat treatment by holding a hot-rolled steel sheet in a temperature range from 620 to 700 °C for not shorter than 10 minutes; cold rolling the heat-treated steel sheet; holding the cold-rolled steel sheet in a temperature range from 880 to 1050 °C for not shorter than 10 seconds and then cooling the steel sheet to a temperature not higher than 450 °C at a cooling rate not lower than 20 °C/s; and, after cooling the steel sheet to a temperature not higher than 450 °C in the cooling step, performing one of the following sub-processes, (A) and (B):

(A) a sub-process for cooling to a temperature not higher than 350 °C and not higher than a martensite transformation start temperature (Ms point) and then reheating and holding in a temperature range from 300 to 450 °C; and
(B) a sub-process for holding in a temperature range from 300 to 450 °C during the cooling without performing reheating.

EFFECTS OF THE INVENTION

[0011] The present invention provides a cold-rolled steel sheet having high strength and good hole expandability.

EMBODIMENTS FOR CARRYING OUT THE INVENTION

[0012] To solve the above-identified problem, the present inventors conducted various research and obtained the following discoveries.

[0013] To increase the strength of a cold-rolled steel sheet, the sheet must be subjected to an appropriate heat treatment to transform the microstructure into a microstructure mainly composed of tempered martensite and bainite. Further, to obtain good hole expandability, it is effective to provide a uniform Mn distribution in the microstructure. Providing a uniform Mn distribution prevents production of the martensite-austenite constituent (MA) during heat treatment. In regions where Mn has concentrated, hardenability increases and thus MA can easily be produced. MA is a very hard structure and can easily provide initiation points for cracks during hole expansion. Preventing production of MA will improve hole expandability.

[0014] Specifically, the microstructure is to be a microstructure containing tempered martensite and bainite in not less than 85 volume % in total and, as seen in a cross section of the steel sheet, the area ratio of regions where the Mn concentration in the microstructure is not lower than 8.0 mass % is to be 0.05 to 1.5 area %. A low area ratio of regions with an Mn concentration not lower than 8.0 mass % (hereinafter referred to as "Mn concentration regions") means a uniform Mn distribution. Reducing the area ratio of Mn concentration regions prevents production of MA to improve hole expandability. On the other hand, if the Mn concentration regions completely disappear, good elongation cannot be provided. Ensuring that Mn concentration regions are still present in a low area ratio (not lower than 0.05 area %) promotes hardening during working of the steel, thereby improving elongation of the steel.

[0015] To provide such a microstructure, the following heat treatment is effective: first, a hot-rolled steel sheet is subjected to a heat treatment where it is held in the temperature range from 620 to 700 °C for not shorter than 10 minutes; this produces cementite in the steel, in which not lower than 10 mass % Mn typically concentrates; this steel sheet is cold rolled and, thereafter, held at a temperature of 880 to 1050 °C to cause Mn in the microstructure to diffuse, providing a uniform Mn distribution; this steel sheet is cooled to a temperature not higher than 450 °C at a cooling rate not lower than 20 °C/s to produce martensite and bainite.

[0016] According to a preferred embodiment, the microstructure is a microstructure further containing ferrite in not less than 5 volume %, and the average crystal grain size of ferrite is not larger than 10.0 pm. Providing a microstructure containing ferrite in not less than 5 volume % will further improve elongation.

[0017] The present invention was made based on these discoveries. Now, a cold-rolled steel sheet according to one embodiment of the present invention will be described.

[Cold-Rolled Steel Sheet]

[Chemical Composition]

[0018] The cold-rolled steel sheet according to one embodiment of the present invention has such a chemical composition as specified below. In the description below, "%" for the content of an element means mass %.

C: 0.10 to 0.30 %

[0019] Carbon (C) improves the strength of steel. On the other hand, if C content is too high, this decreases elongation of the steel. In view of this, C content is to be 0.10 to 0.30 %. A lower limit of C content is preferably 0.12 %, and more preferably 0.15 %. An upper limit of C content is preferably 0.25 %, and more preferably 0.20 %.

Si: up to 2.50 %

[0020] Silicon (Si) is a solid-solution strengthening element; however, an excessive content decreases the hot workability of the steel. In view of this, Si content is to be not higher than 2.50 %. An upper limit of Si content is preferably 2.00 %, and more preferably 1.50 %. A lower limit of Si content is preferably 0.10 %, and more preferably 0.30 %.

Mn: 0.50 to 3.50 %

[0021] Manganese (Mn) increases the hardenability of steel to improve the strength of the steel. On the other hand, if Mn content is too high, this decreases elongation of the steel. In view of this, Mn content is to be 0.50 to 3.50 %. A lower limit of Mn content is preferably 0.80 %, more preferably 1.20 %, yet more preferably 1.55 %, and still more preferably 1.60 %. An upper limit of Mn content is preferably 3.30 %, more preferably 3.00 %, and yet more preferably 2.80 %.

P: up to 0.100 %

[0022] Phosphorus (P) is an impurity. P segregates on grain boundaries to decrease elongation of the steel. In view of this, P content is to be not higher than 0.100 %. P content is preferably not higher than 0.050 %, and more preferably not higher than 0.030 %.

S: up to 0.020 %

[0023] Sulfur (S) is an impurity. S decreases the hot workability of steel. In view of this, S content is to be not higher than 0.020 %. S content is preferably not higher than 0.015 %, and more preferably not higher than 0.010 %.

Al: 0.010 to 0.100 %

[0024] Aluminum (Al) is contained in steel to serve as a deoxidizer. On the other hand, if Al content is too high, this produces inclusions, thus decreasing elongation of the steel. In view of this, Al content is to be 0.010 to 0.100 %. A lower limit of Al content is preferably 0.015 %, and more preferably 0.020 %. An upper limit of Al content is preferably 0.080 %, and more preferably 0.060 %.

N: up to 0.0100 %

[0025] Nitrogen (N) is an impurity. N decreases elongation of the steel. In view of this, N content is to be not higher than 0.0100 %. An upper limit of N content is preferably 0.0060 %, and more preferably 0.0040 %. On the other hand, excessively reducing N increases manufacturing costs. A lower limit of N content is preferably 0.0005 %, and more preferably 0.0010 %.

[0026] The chemical composition of the cold-rolled steel sheet according to the present embodiment may include one or more elements selected from the group consisting of Ti, Nb, V, Mo, W, B, Ca, Mg and REM. All of these elements are optional elements. In other words, the chemical composition of the cold-rolled steel sheet according to the present embodiment may not include all of Ti, Nb, V, Mo, W, B, Ca, Mg and REM, or may include none of them.

Ti: 0 to 0.100 %
Nb: 0 to 0.100 %
V: 0 to 0.50 %

Mo: 0 to 0.50 %
W: 0 to 0.50 %

[0027] Titanium (Ti), niobium (Nb), vanadium (V), molybdenum (Mo), and tungsten (W) all have the effect of improving the strength of steel by forming carbides. This effect is produced if small amounts of Ti, Nb, V, Mo, and W are contained in the steel. On the other hand, excessive contents of Ti, Nb, V, Mo, and W decrease elongation of the steel. In view of this, each of the contents of Ti and Nb is to be 0 to 0.100 %, and each of the contents of V, Mo and W is to be 0 to 0.50 %. A lower limit for Ti and Nb is preferably 0.005 %. An upper limit for Ti and Nb is preferably 0.060 %, and more preferably 0.040 %. A lower limit for V, Mo and W is preferably 0.01 %. An upper limit for V, Mo and W is preferably 0.40 % and more preferably 0.30 %.

B: 0 to 0.0050 %

[0028] Boron (B) increases hardenability to improve the strength of the steel. This effect is produced if a small amount of B is contained in the steel. On the other hand, an excessive B content decreases elongation of the steel. In view of this, B content is to be 0 to 0.0050 %. A lower limit of B content is preferably 0.0003 %. An upper limit of B content is preferably 0.0040 %, and more preferably 0.0030 %.

Ca: 0 to 0.0100 %
Mg: 0 to 0.0100 %
REM: 0 to 0.0100 %

[0029] Calcium (Ca), magnesium (Mg) and rare earth elements (REM) all improve the hot workability of steel. This effect is produced if small amounts of Ca, Mg and REM are contained. On the other hand, excessive contents of Ca, Mg and REM produce inclusions, thus decreasing elongation of the steel. In view of this, each of the contents of Ca, Mg and REM is to be 0 to 0.0100 %. A lower limit of each of the contents of Ca, Mg and REM is preferably 0.0001 %. An upper limit of each of the contents of Ca, Mg and REM is preferably 0.0060 %, and more preferably 0.0040 %. REM is the collective term for a total of 17 elements, namely, Sc, Y and the lanthanoids, and REM content means the total amount of these elements.

[0030] The balance of the chemical composition of the cold-rolled steel sheet according to the present embodiment is Fe and impurities. Impurity as used herein means an element originating from ore or scrap used as raw material for steel or an element that has entered from the environment or the like during the manufacturing process. Although not limiting, examples of impurities include Cu, Ni, Cr and O.

[Microstructure]

[0031] The microstructure of the cold-rolled steel sheet according to the present embodiment contains tempered martensite and bainite in not less than 85 volume % in total. The required strength cannot be obtained if the total volume ratio of tempered martensite and bainite is lower than 85 %. As used herein, "bainite" encompasses bainite that has undergone tempering. Part of the bainite in the microstructure of the cold-rolled steel sheet according to the present embodiment may be tempered. Further, even though cementite is present in the tempered martensite and bainite, the cementite in the tempered martensite and bainite is not treated as an independent structure, and its volume is included in the total volume of the tempered martensite and bainite.

[0032] The average particle size of the cementite contained in the tempered martensite and bainite is larger than 30 nm. The average particle size of cementite is measured by taking, from a cold-rolled steel sheet, an extraction replica film and then using transmission electron microscopy (with an accelerating voltage of 200 kV) to observe three or more fields of view at a magnification for observation of 10,000 to 100,000 times. An average particle size means an equivalent circle diameter. If the microstructure is mainly composed of martensite containing no cementite (i.e., mainly composed of as-quenched martensite), it is not possible to provide sufficient hole expandability. The average particle size of cementite is preferably larger than 50 nm.

[0033] In the cold-rolled steel sheet according to the present embodiment, the regions where the Mn concentration in the microstructure is not lower than 8.0 mass % are present in 0.05 to 1.5 area %. A low area ratio of the regions with an Mn concentration not lower than 8.0 mass % (hereinafter referred to as "Mn concentration regions") means a uniform Mn distribution. Reducing the area ratio of Mn concentration regions prevents production of MA to improve hole expandability. On the other hand, if the Mn concentration regions completely disappear, good elongation cannot be provided. Ensuring that Mn concentration regions are still present in not less than 0.05 area % promotes hardening during working of the steel, thereby improving elongation of the steel.

[0034] A lower limit for Mn concentration regions is preferably 0.10 area %, and more preferably 0.20 area %. An upper limit for Mn concentration regions is preferably 1.0 area %.

[0035] The microstructure of the cold-rolled steel sheet according to the present embodiment preferably further contains ferrite in not less than 5 volume %, where the average crystal grain size of the ferrite is not larger than 10.0 pm. Providing a microstructure containing ferrite in not less than 5 volume % further improves elongation. A lower limit of the volume ratio of ferrite is more preferably 10 %. However, the effect of improving elongation cannot be produced if the average crystal grain size of ferrite is too large. An upper limit of the average crystal grain size of ferrite is more preferably 5.0 pm.

[0036] Although not limiting, the balance of the microstructure of the cold-rolled steel sheet according to the present embodiment may be pearlite, MA, and/or retained austenite, for example. In the microstructure of the cold-rolled steel sheet according to the present embodiment, the volume ratio of the balance excluding martensite, tempered martensite and ferrite is not higher than 5 %. An upper limit of the volume ratio of the balance is preferably 3 %.

[0037] The cold-rolled steel sheet according to the present embodiment preferably has a tensile strength not lower than 980 MPa. A lower limit of tensile strength is more preferably 1050 MPa, and more preferably 1180 MPa. Although not limiting, an upper limit of tensile strength may be 1450 MPa, for example.

[0038] The cold-rolled steel sheet according to the present embodiment preferably has a breaking elongation not lower than 8.0 %. A lower limit of breaking elongation is more preferably 10.0 %.

[Method of Manufacturing Cold-Rolled Steel Sheet]

[0039] Next, an exemplary method of manufacturing the above-described cold-rolled steel sheet will be described. The manufacturing method described below is merely illustrative, and is not intended to limit the method of manufacturing the cold-rolled steel sheet according to the present embodiment.

[0040] A hot-rolled steel sheet having such a chemical composition as specified above is prepared. The hot-rolled steel sheet may be produced by, for example, preparing a slab having such a chemical composition as specified above, hot rolling the slab by a common method, and coiling the resulting sheet. The method is not limited to any particular reduction in sectional area during hot rolling, sheet thickness after rolling, method of cooling to room temperature, or coiling conditions, for example.

[0041] The hot-rolled steel sheet is held in the temperature range from 620 to 700 °C for not shorter than 10 minutes. This heat treatment will be hereinafter referred to as "post-hot-rolling heat treatment". This post-hot-rolling heat treatment produces cementite in the steel, in which Mn concentrates. Mn does not sufficiently concentrate if the holding temperature is too low or the holding time is too short, in which case it may not be possible to ensure that the area ratio of Mn concentration regions in the microstructure of the eventual cold-rolled steel sheet is not lower than 0.05 area %. On the other hand, if the holding temperature is too high, austenite may be produced in portions of the microstructure, leading to insufficient Mn concentration. A lower limit of the holding temperature for the post-hot-rolling heat treatment is preferably 630 °C. An upper limit of the holding temperature for the post-hot-rolling heat treatment is preferably 680 °C. A lower limit of the holding time for the post-hot-rolling heat treatment is preferably 30 minutes, and more preferably 60 minutes. Although not limiting, an upper limit of the holding time for the post-hot-rolling heat treatment may be 300 minutes, for example. Any cooling rate after the holding may be used.

[0042] Further, depending on the thermodynamic properties of the cementite, performing the post-hot-rolling heat treatment near 600 °C may excessively increase the Mn concentration in the cementite. As such, if the temperature for the post-hot-rolling heat treatment is lower than 620 °C, local Mn concentration may be excessively high, which may make it impossible to cause Mn to sufficiently diffuse during the post-cold-rolling heat treatment, in which case it may not be possible to ensure that the area ratio of Mn concentration regions is not higher than 1.5 %.

[0043] The steel sheet subjected to the post-hot-rolling heat treatment is subjected to cold rolling. The reduction in sheet thickness during the cold rolling may be 30 to 80 %, for example.

[0044] The steel sheet subjected to the cold rolling is held in the temperature range from 880 to 1050 °C for not shorter than 10 seconds and, thereafter, cooled to a temperature not higher than 450 °C at a cooling rate not lower than 20 °C/s. This heat treatment will be hereinafter referred to as "post-cold-rolling heat treatment".

[0045] As the steel sheet is held in the temperature range from 880 to 1050 °C for not shorter than 10 seconds, Mn in the microstructure diffuses, providing a uniform Mn concentration distribution. Mn does not sufficiently diffuse if the holding temperature is too low or the holding time is too short, in which case it may not be possible to ensure that the area ratio of Mn concentration regions in the microstructure of the eventual cold-rolled steel sheet is not higher than 1.5 area %. On the other hand, if the holding temperature is too high, Mn diffuses and thus decreases concentration in the Mn concentration regions to below the lower limit of Mn concentration. A lower limit of the holding temperature for the post-cold-rolling heat treatment is preferably 900 °C, and more preferably 920 °C. An upper limit of the holding temperature for the post-cold-rolling heat treatment is preferably 1000 °C. A lower limit of the holding time for the post-cold-rolling heat treatment is preferably 20 seconds, and more preferably 30 seconds. Although not limiting, an upper limit of the holding time for the post-cold-rolling heat treatment may be 300 seconds, for example.

[0046] After the steel sheet has been held in the temperature range from 880 to 1050 °C, it is cooled to a temperature not higher than 450 °C at a cooling rate not lower than 20 °C/s. At this time, part of the microstructure transforms to martensite.

A microstructure containing ferrite in not less than 5 volume % is obtained if the cooling rate at this time is 20 to 30 °C/s, which is relatively low. If the cooling rate is lower than 20 °C/s, an excessive amount of ferrite is produced, in which case it is not possible to ensure that the total volume ratio of tempered martensite and bainite in the microstructure of the eventual cold-rolled steel sheet is not lower than 85 %. Although not limiting, an upper limit of the cooling rate may be 200 °C/s, for example.

[0047] After the sheet has been cooled to a temperature not higher than 450 °C, one of the following sub-processes is further performed: (A) the sheet is cooled to a temperature not higher than 350 °C and not higher than the martensite transform start temperature (Ms point) and, thereafter, the sheet is reheated and held in the temperature range from 300 to 450 °C for a predetermined period of time (preferably not shorter than 100 seconds) ("quench & partitioning process"); and (B) the sheet is held in the temperature range from 300 to 450 °C during the cooling for a predetermined period of time (preferably not shorter than 100 seconds), without being reheated ("austempering process").

[0048] The cementite that precipitated during the post-hot-rolling heat treatment is dissolved during the post-cold-rolling heat treatment. The amount of dissolution of cementite at this time is to be not smaller than 90 volume % of the cementite prior to the post-cold-rolling heat treatment, and preferably not smaller than 95 volume %. After the post-cold-rolling heat treatment and the subsequent cooling, one of sub-processes (A) and (B) above is performed to cause cementite to precipitate once again in the microstructure. This results in a microstructure containing tempered martensite and bainite in not less than 85 volume % in total. If the holding temperature is lower than 300 °C, cementite may not precipitate in a sufficient amount (i.e., the average particle size of cementite may not be larger than 30 nm).

[0049] The above-described process results in the cold-rolled steel sheet according to the present embodiment. The manufacturing method described above provides a cold-rolled steel sheet containing tempered martensite and bainite in not less than 85 volume % in total and having a microstructure with structures other than tempered martensite, bainite and ferrite in not more than 5 volume %, wherein the regions where the Mn concentration in the microstructure is not lower than 8.0 mass % are present in 0.05 to 1.5 area %.

[0050] A cold-rolled steel sheet according to one embodiment of the present invention, as well as a method of manufacturing the same, have been described. The present embodiment provides a cold-rolled steel sheet with high strength and good hole expandability.

EXAMPLES

[0051] The present invention will be described more specifically below by means of examples. The present invention is not limited to these examples.

[0052] 180 kg steel ingots having the chemical compositions shown in Table 1 were smelted in a high-frequency vacuum melting furnace and subjected to hot forging to produce slabs with a thickness of 30 mm. Each slab thus obtained was hot rolled by a hot-rolling test instrument to a finish temperature of 850 to 900 °C to produce a hot-rolled steel sheet with a thickness of 2.0 mm. After the hot rolling had been completed and 3 to 10 seconds had passed, the steel sheet was cooled to a wind-up temperature of 200 to 650 °C and, thereafter, cooled to a temperature not higher than 200 °C at a cooling rate of 20 °C/s to imitate the coiling of the steel sheet, thus producing a hot-rolled steel sheet.

[Table 1]

[0053]

TABLE 1

Steel type	Chemical composition (in mass %, balance Fe and impurities)							
	C	Si	Mn	P	S	sol. Al	N	Others
A	0.15	0.92	2.81	0.013	0.005	0.036	0.0021	-
B	0.17	1.43	2.34	0.014	0.004	0.021	0.0034	Ti: 0.023
C	0.13	0.64	1.77	0.017	0.003	0.041	0.0020	V: 0.21
D	0.19	0.74	1.55	0.011	0.007	0.028	0.0023	Mo: 0.23, Mg: 0.0026
E	0.23	1.18	2.53	0.022	0.004	0.033	0.0025	Nb: 0.022
F	0.14	0.68	2.11	0.015	0.006	0.039	0.0034	W: 0.11, REM: 0.0019
G	0.20	0.66	3.23	0.013	0.004	0.027	0.0027	Ti: 0.019, Nb: 0.011, B: 0.0015
H	0.22	0.62	1.87	0.019	0.003	0.039	0.0030	Ca: 0.0033

(continued)

Steel type	Chemical composition (in mass %, balance Fe and impurities)							
	C	Si	Mn	P	S	sol. Al	N	Others
I	0.18	0.38	0.40	0.011	0.007	0.024	0.0028	-
J	0.01	0.02	0.17	0.012	0.005	0.027	0.0034	-

[0054] The hot-rolled steel sheet was subjected to heat treatment (i.e., post-hot-rolling heat treatment) at the relevant temperature and for the relevant holding time shown in Table 2 and, thereafter, subjected to cold rolling at a reduction in sheet thickness (i.e., reduction during cold rolling) of 50 % to produce a piece of steel material with a thickness of 1.0 mm.

[Table 2]

[0055]

TABLE 2

Test No.	Steel type	Post-hot-rolling heat treatment		Cold rolling	Post-cold-rolling heat treatment			
		Holding temp. (°C)	Holding time (min)	Cold-rolling ratio (%)	Holding temp. (°C) I	Holding time (s)	Cooling rate (°C/s)	After cooling at 450 °C
1	A	650	80	50	900	60	40	quench & partitioning
2	A	650	80	50	950	60	40	quench & partitioning
3	A	650	80	50	1000	60	40	quench & partitioning
4	A	650	30	50	900	60	40	quench & partitioning
5	A	650	120	50	900	60	40	quench & partitioning
6	A	650	80	50	900	45	25	quench & partitioning
7	A	650	80	50	900	35	25	quench & partitioning
8	A	650	120	50	920	60	40	austempering
9	B	650	80	50	950	80	35	austempering
10	B	650	80	50	950	120	35	austempering
11	C	650	80	50	950	60	20	austempering
12	D	650	80	50	900	60	20	quench & partitioning
13	E	650	80	50	920	60	50	quench & partitioning
14	F	650	80	50	920	60	50	quench & partitioning
15	G	650	80	50	900	60	70	quench & partitioning
16	H	650	80	50	900	60	100	austempering
17	A	650	80	50	830	60	40	quench & partitioning
18	A	550	80	50	950	60	40	quench & partitioning
19	A	650	80	50	800	60	40	quench & partitioning
20	A	650	80	50	950	60	5	quench & partitioning
21	A	650	80	50	950	5	40	quench & partitioning
22	A	600	120	50	920	60	40	austempering
2.3	A	650	120	50	920	60	40	-
24	B	650	80	50	820	120	40	austempering

(continued)

Test No.	Steel type	Post-hot-rolling heat treatment		Cold rolling	Post-cold-rolling heat treatment			
		Holding temp. (°C)	Holding time (min)	Cold-rolling ratio (%)	Holding temp. (°C) I	Holding time (s)	Cooling rate (°C/s)	After cooling at 450 °C
25	C	650	80	50	830	60	40	austempering
26	D	650	80	50	900	3	40	quench & partitioning
27	E	400	80	50	830	60	40	quench & partitioning
28	F	650	80	50	920	60	5	quench & partitioning
29	G	650	80	50	830	60	70	quench & partitioning
30	H	650	80	50	830	60	100	austempering
31	I	650	80	50	950	60	40	quench & partitioning
32	J	650	80	50	950	60	40	austempering

[0056] From the piece of steel material thus obtained were taken test samples with a width of 160 mm and a length of 230 mm. Each test sample thus obtained was subjected to heat treatment (i.e., annealing) under the relevant conditions indicated in the "Post-cold-rolling heat treatment" columns in Table 2.

[0057] Specifically, the test sample was heated to the relevant temperature in Table 2 and soaked for the relevant holding time shown in Table 2. After the soaking, the test sample was cooled to a temperature not higher than 450 °C at the relevant cooling rate in Table 2. Furthermore, the test samples labeled Test Nos. 1 to 7, 12 to 15, 17 to 21, 26 to 29 and 31 were cooled to a temperature not higher than 350 °C and not higher than the martensite transformation start temperature (Ms point) and then reheated and held in the temperature range from 350 to 400 °C for 300 seconds (quench & partitioning process), before being cooled to room temperature. The test samples labeled Test Nos. 8 to 11, 16, 22, 24, 25, 30 and 32 were subjected to a sub-process for holding in the temperature range from 350 to 400 °C for 300 seconds during the cooling without reheating (austempering) before cooling to room temperature. The test sample labeled Test No. 23 was cooled to room temperature without being subjected to any of the above-mentioned sub-processes.

[0058] The test samples after heat treatment were used for microstructure observation, tensile testing and hole expansion testing.

[0059] To evaluate tensile properties, from each test sample after heat treatment were taken two JIS No. 5 test specimens with a longitudinal direction parallel to the direction of rolling (i.e., L-direction), which were tested at a tension rate of 10 mm/min. From the results, tensile strength (TS/MPa) and breaking elongation (tEL/%) were determined. The tensile strength and breaking elongation were represented by the average values for the two tensile test specimens.

[0060] To measure hole expansion ratio, two 90 mm × 90 mm test specimens were taken from each test sample after heat treatment, and a punching hole was formed in the middle with the original hole diameter d_0 = 10 mm. This hole was expanded using a conical punch with a tip angle of 60°; the expanding was stopped when the edge of the punched hole developed a crack extending through the sheet thickness, and the load was removed. In the test specimen, the hole diameters in the direction parallel to, the direction perpendicular to, and two directions angled at 45° relative to, the direction of rolling were measured, and the average thereof was treated as the hole diameter after hole expansion, d. The hole expansion ratio HER was evaluated by the expression provided below. The hole expansion ratio HER was represented by the average for the two test specimens.

$$\mathrm{HER}\ (\%) = (\mathrm{d} - \mathrm{d}_0) / \mathrm{d}_0 \times 100$$

[0061] The microstructure of the test sample after heat treatment was measured by the following method.

[0062] First, from each test sample after heat treatment was taken an observation sample with an observation surface represented by a cut surface parallel to the direction of rolling and the sheet-thickness direction. Electron backscatter diffraction (EBSD) analysis was performed in a 200 pmL × 100 pmT region in the L-cut surface of the test sample (i.e., cut surface parallel to the direction of rolling and the sheet-thickness direction). The scan step was 0.1 pm, and the measurement points were on a hexagonal grid.

[0063] The EBSD data was analyzed, where crystal phases were identified in the EBSD pattern for the measurement points; a region identified as in the BCC phase was classified as tempered martensite, bainite or ferrite; a region identified as in the FCC phase was classified as retained austenite; and a region where the microstructure could not be identified (e.g., with an EBSD system from TSL Solutions Co. Ltd., the confidential index value was lower than 0.1) was classified as cementite contained in MA or pearlite.

[0064] The regions identified as in the BCC phase were further classified as ferrite and non-ferrite (i.e., tempered martensite or bainite) in the following manner.

[0065] In the EBSD data, a grain boundary was defined as a boundary with a crystal misorientation not smaller than 15 °, and the region surrounded by grain boundaries was treated as a crystal grain. Where the number of EBSD measurement points contained inside a crystal grain in the BCC phase is denoted by *m,* and a rotation matrix representing the crystal orientation at an individual measurement point is denoted by P_j(j= 1 ... m), all the combinations of the crystal misorientations $\Delta\theta$ (in degrees) between adjacent measurement points were calculated using the following expressions, and the average value of these misorientations, M, was determined.

[Mathematical Expression 1]

$$\mathbf{D} = \mathbf{R}_\mathrm{k} \cdot \mathbf{P}_\mathrm{i} \cdot \mathbf{P}_\mathrm{j}$$

$$\Delta\theta = \cos^{-1}\big((\mathrm{D}[1,1] + \mathrm{D}[2,2] + \mathrm{D}[3,3] - 1)/2\big)$$

[0066] P_i and P_j are rotation matrices that can be calculated using the Euler angles for each measurement point determined by EBSD measurement. Specifically, P_i was obtained by substituting the Euler angles (φ_1, Φ and φ_2) for the *i*th measurement point (i = 1 ... *m*) obtained by EBSD measurement into the following expression.

[Mathematical Expression 2]

$$\mathbf{P}_i = \begin{pmatrix} \cos\varphi_2 & \sin\varphi_2 & 0 \\ -\sin\varphi_2 & \cos\varphi_2 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\Phi & \sin\Phi \\ 0 & -\sin\Phi & \cos\Phi \end{pmatrix} \begin{pmatrix} \cos\varphi_1 & \sin\varphi_1 & 0 \\ -\sin\varphi_1 & \cos\varphi_1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$= \begin{pmatrix} \cos\varphi_1\cos\varphi_2 - \sin\varphi_1\sin\varphi_2\cos\Phi & \sin\varphi_1\cos\varphi_2 + \cos\varphi_1\sin\varphi_2\cos\Phi & \sin\varphi_2\sin\Phi \\ -\cos\varphi_1\sin\varphi_2 - \sin\varphi_1\cos\varphi_2\cos\Phi & -\sin\varphi_1\sin\varphi_2 + \cos\varphi_1\cos\varphi_2\cos\Phi & \cos\varphi_2\sin\Phi \\ \sin\varphi_1\sin\Phi & -\cos\varphi_1\sin\Phi & \cos\Phi \end{pmatrix}$$

[0067] R_k (k= 1 ... 24) is a rotation matrix for conversion of the basis vectors of a cubic crystal, where such a value of k was selected as to minimize the rotational angle of $R_k \cdot P_i \cdot P_j$. Adjacent measurement points were selected for the *i*th and jth measurements. $D[i,i]$ expresses the value of the component at the *i*th row and *i*th column of a 3 × 3 matrix D. A BCC crystal grain with an average crystal misorientation *M* not larger than 0.5° was treated as ferrite, and a crystal grain in excess of 0.5° was treated as tempered martensite or bainite.

[0068] After the structures were thus classified, the proportion of the measurement points determined to be in the non-ferrite BCC phase (i.e., tempered martensite or bainite) and the proportion of the measurement points determined to be ferrite in all the measurement points were determined, and these proportions were treated as the total volume ratio of tempered martensite / bainite and the volume ratio of ferrite, respectively. The remaining regions contained pearlite, MA and retained austenite (i.e., regions identified as in the FCC phase based on EBSD), and were classified as "other regions".

[0069] The average crystal grain size of ferrite was determined by calculating the average value *d* of equivalent circle diameters from EBSD measurements using the expression indicated below. However, a test sample with a volume ratio of ferrite lower than 5 % was excluded from evaluation.

[Mathematical Expression 3]

$$d = \frac{\sum_i A_i \times d_i}{\sum_i A_i}$$

[0070] Here, A_i is the area of the *i*th ferrite crystal grain determined through analysis of EBSD data, and d_i is the equivalent circle diameter of the *i*th ferrite crystal grain. An equivalent circle diameter means the diameter of a circle with an area equal to the area of the *i*th ferrite crystal grain (= A_i).

[0071] Using the same samples for observation as mentioned above, mapping measurement of Mn concentration in the microstructure was performed using an electron probe microanalyzer (EPMA). JXA-8530F from JEOL Ltd. was used, where the accelerating voltage of the electron beam was 7 kV, the amount of current for illumination was 20 nA; a 30 pm × 30 pm region in the observation surface was divided into sub-regions that each contained 500 points × 500 points (arranged on a square lattice) and the electron beam was scanned, and the fluorescent X-ray (i.e., Kα line) of Mn generated from each point was measured by a wavelength resolving detector.

[0072] From the obtained counts of the fluorescent X-ray, I, the Mn concentration X_{Mn} for each point was determined using the following evaluation expression based on ZAF correction:

$$X_{\mathrm{Mn}} = I / I_0 \times Z \times A \times F.$$

[0073] Here, I_0 indicates the count of a fluorescent X-ray (i.e., Kα line) obtained from a pure-Mn standard sample in advance by EPMA measurement under the same electron beam conditions. Z, A and F indicate atomic-number correction, absorption correction coefficient and fluorescent correction coefficient, respectively, where the values used were known values determined based on the illumination conditions for the electron beam for EPMA and the component values of steel in accordance with SOEJIMA, Hiroyoshi: "Electron Probe Microanalysis", Nikkan Kogyo Shimbun, Ltd.

[0074] From the Mn concentration distribution obtained was determined the proportion of measurement points with an Mn concentration not lower than 8.0 mass % in all the measurement points (250,000 points), and was treated as the area ratio of regions with an Mn concentration not lower than 8.0 mass %.

[0075] The results are shown in Table 3. In Table 3, "TM+B" indicates the total volume ratio of tempered martensite and bainite, and "α" indicates the volume ratio of ferrite. "A*" indicates the area ratio of regions with an Mn concentration not lower than 8.0 mass %.

[Table 3]

[0076]

TABLE 3

Test No.	Steel type	Metal microstructure					Mechanical properties			
		Volume ratio (%)			Ferrite avg. crystal grain size (μm)	A* (%)	TS (MPa)	tEL (%)	HER (%)	
		TM+B	α	Balance						
1	A	97	2	1	-	0.8	1154	9.2	43.3	inv. ex.
2	A	96	3	1	-	0.3	1146	9.0	45.9	
3	A	98	1	1	-	0.2	1168	102	46.8	
4	A	96	3	1	-	0.3	1148	10.4	49.5	
5	A	97	2	1	-	0.8	1145	9.2	42.5	
6	A	89	10	1	4.4	0.4	1097	11.6	42.0	
7	A	86	13	1	4.3	0.7	1036	13.9	49.0	
8	A	97	2	1	-	0.9	1058	14.3	41.5	
9	B	96	3	1	-	0.6	1218	9.5	59.5	
10	B	95	4	1	-	0.2	1202	10.4	40.4	
11	C	91	8	1	2.5	0.2	1011	13.2	40.4	
12	D	88	11	1	2.1	0.8	1233	10.7	41.2	
13	E	95	4	1	-	0.9	1441	8.8	53.8	
14	F	98	1	1	-	0.5	1073	9.3	47.7	
15	G	96	3	1	-	0.6	1359	8.1	43.1	
16	H	95	4	1	-	0.4	1402	8.9	54.3	

(continued)

Test No.	Steel type	Metal microstructure					Mechanical properties			
		Volume ratio (%)			Ferrite avg. crystal grain size (μm)	A* (%)	TS (MPa)	tEL (%)	HER (%)	
		TM+B	α	Balance						
17	A	86	11	3	2.8	3.4	981	11.7	32.6	comp. ex.
18	A	95	2	3	3.2	0.0	1135	7.4	26.7	
19	A	86	11	3	3.3	3.7	998	11.8	25.2	
20	A	76	23	1	7.2	0.4	963	11.3	29.4	
21	A	94	3	3	-	3.0	1162	9.4	31.9	
22	A	95	3	2	-	1.8	1065	13.9	30.6	
23	A	26	9	65	-	0.9	1339	6.9	38.2	
24	B	87	10	3	-	2.9	1134	10.3	34.2	
25	C	86	12	2	3.3	2.5	1018	10.3	32.4	
26	D	94	3	3	-	3.2	1297	8.9	25.1	
27	E	86	12	2	7.9	0.0	1310	6.5	36.8	
28	F	78	20	2	2.7	0.6	949	11.5	28.9	
29	G	86	11	3	3.7	3.2	1210	8.3	32.3	
30	H	85	11	4	2.7	3.9	1229	9.7	28.0	
31	I	2	91	7	9.2	0.3	542	32.0	55.0	
32	J	0	99	1	19.7	0.0	289	53.0	183.0	

A : Area ratio of regions with an Mn concentration not lower than 8.0 mass %

[0077] As shown in Tables 1 to 3, each of the test samples labeled Test Nos. 1 to 16 contained tempered martensite and bainite in not less than 85 volume % in total, and had a microstructure with the structures other than tempered martensite, bainite and ferrite in not more than 5 mass %, wherein the regions where the Mn concentration in the microstructure was not lower than 8.0 mass % were present in 0.05 to 1.5 area %. In each of these test samples, the average particle size of cementite contained in tempered martensite and bainite was larger than 50 nm. These test samples had a tensile strength not lower than 980 MPa, an elongation not lower than 8.0 %, and a hole expansion ratio not lower than 40.0 %. In particular, the test samples labeled Test Nos. 6, 7, 11 and 12 had a microstructure further containing ferrite in not less than 5 volume %, where the average crystal grain size of ferrite was not larger than 10.0 pm. These test samples had particularly good elongation.

[0078] In contrast, in each of the test samples labeled Test Nos. 17, 19, 21, 22, 24 to 26, 29 and 30, the regions where the Mn concentration in the microstructure was not lower than 8.0 mass % were present in more than 1.5 area %, and the hole expansion ratio was lower than 40.0 %. In the test samples labeled Test Nos. 17, 19, 24, 25, 27, 29 and 30, the area ratio of Mn concentration regions was high presumably because the holding temperature for the post-cold-rolling heat treatment was too low. In the test samples labeled Test No. 21 and 26, the area ratio of Mn concentration regions was high presumably because the holding time for the post-cold-rolling heat treatment was too short. In the test sample labeled Test No. 22, the area ratio of Mn concentration regions was high presumably because the temperature for the post-hot-rolling heat treatment was near 600 °C.

[0079] In the test samples labeled Test Nos. 18 and 27, the regions where the Mn concentration in the microstructure was not lower than 8.0 mass % were present in less than 0.05 area %, and the hole expansion ratio was lower than 40.0 %. The area ratio of Mn concentration regions of these test samples was low presumably because the temperature for the post-hot-rolling heat treatment was too low and thus Mn did not concentrate in the cementite in the steel.

[0080] In each of the test samples labeled Test Nos. 20, 28, 31 and 32, the total volume ratio of tempered martensite and bainite was lower than 85 %, and the tensile strength was lower than 980 MPa. In the test samples labeled Test Nos. 20 and 28, the total volume ratio of tempered martensite and bainite was lower than 85 % presumably because the cooling rate for the post-cold rolling heat treatment was too low. Further, in these test samples, an excessive amount of ferrite was produced, which contributed to a hole expansion ratio lower than 40.0 %. In the test samples labeled Test Nos. 31 and 32, the total volume ratio of tempered martensite and bainite was lower than 85 % presumably because the Mn or C content in the steel material was too low.

[0081] In the test sample labeled Test No. 23, the total volume ratio of tempered martensite and bainite was lower than 85 %, and the hole expansion ratio was lower than 40.0 %. In the test sample labeled Test No. 23, the total volume ratio of tempered martensite and bainite was lower than 85 % presumably because the sample was cooled to room temperature without being subjected to any of the quench & partitioning process and austempering such that a large portion of the microstructure became martensite without precipitation of cementite.

[0082] Although embodiments of the present invention have been described, the above-described embodiments are merely illustrative examples useful for carrying out the present invention. Thus, the present invention is not limited to the above-described embodiments, and the above-described embodiments, when carried out, may be modified as appropriate without departing from the spirit of the invention.

Claims

1. A cold-rolled steel sheet having a chemical composition of, in mass %:

0.10 to 0.30 % C;
up to 2.50 % Si;
0.50 to 3.50 % Mn;
up to 0.100 % P;
up to 0.020 % S;
0.010 to 0.100 % Al;
up to 0.0100 % N;
0 to 0.100 % Ti;
0 to 0.100 % Nb;
0 to 0.50 % V;
0 to 0.50 % Mo;
0 to 0.50 % W;
0 to 0.0050 % B;
0 to 0.0100 % Ca;
0 to 0.0100 % Mg;
0 to 0.0100 % REM; and
balance Fe and impurities,
a microstructure containing tempered martensite and bainite in not less than 85 volume % in total, a structure other than the tempered martensite, bainite and ferrite being present in not more than 5 volume %,
regions where an Mn concentration in the microstructure is not lower than 8.0 mass % being present in 0.05 to 1.5 area %.

2. The cold-rolled steel sheet according to claim 1, wherein:

the microstructure further contains ferrite in not less than 5 volume %; and
an average crystal grain size of the ferrite is not larger than 10.0 pm.

3. The cold-rolled steel sheet according to claim 1 or 2, wherein the chemical composition includes one or more selected from the group consisting of, in mass %:

0.005 to 0.100 % Ti;
0.005 to 0.100 % Nb;
0.01 to 0.50 % V;
0.01 to 0.50 % Mo; and
0.01 to 0.50 % W.

4. The cold-rolled steel sheet according to claim 1 or 2, wherein the chemical composition includes, in mass %: 0.0003 to 0.0050 % B.

5. The cold-rolled steel sheet according to claim 1 or 2, wherein the chemical composition includes one or more selected from the group consisting of, in mass %:

0.0001 to 0.0100 % Ca;
0.0001 to 0.0100 % Mg; and
0.0001 to 0.0100 % REM.

6. The cold-rolled steel sheet according to claim 1 or 2, wherein the tempered martensite and bainite of the microstructure contains cementite with an average particle size larger than 30 nm.

7. A method of manufacturing the cold-rolled steel sheet according to claim 1 or 2, comprising:

performing a heat treatment by holding a hot-rolled steel sheet in a temperature range from 620 to 700 °C for not shorter than 10 minutes;
cold rolling the heat-treated steel sheet;
holding the cold-rolled steel sheet in a temperature range from 880 to 1050 °C for not shorter than 10 seconds and then cooling the steel sheet to a temperature not higher than 450 °C at a cooling rate not lower than 20 °C/s; and,
after cooling the steel sheet to a temperature not higher than 450 °C in the cooling step, performing one of the following sub-processes, (A) and (B):

(A) a sub-process for cooling to a temperature not higher than 350 °C and not higher than a martensite transformation start temperature (Ms point) and then reheating and holding in a temperature range from 300 to 450 °C; and
(B) a sub-process for holding in a temperature range from 300 to 450 °C during the cooling without performing reheating.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/010911

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/14***(2006.01)i
FI: C22C38/00 301S; C22C38/14; C21D9/46 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)

C22C38/00-38/60; C21D8/02; C21D9/46

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 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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.
A	WO 2020/136988 A1 (JFE STEEL CORP.) 02 July 2020 (2020-07-02) claims, tables 1-3	1-7
A	WO 2016/129550 A1 (KABUSHIKI KAISHA KOBE SEIKO SHO) 18 August 2016 (2016-08-18) claims, paragraphs [0039]-[0045], tables 1-3	1-7

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:

"A"	document defining the general state of the art which is not considered to be of particular relevance
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"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 May 2023	**13 June 2023**

Name and mailing address of the ISA/JP

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Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/010911

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2020/136988 A1	02 July 2020	EP 3904552 A1 claims, tables 1-3 US 2022/0074013 A1 CN 113227428 A	
WO 2016/129550 A1	18 August 2016	US 2019/0153575 A1 claims, paragraphs [0084]-[0093], tables 1-3 CN 107208228 A JP 2016-153524 A	

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

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 2018030502 A1 **[0003] [0007]**
- JP 2016194139 A **[0004] [0007]**
- JP 2015193897 A **[0005] [0007]**
- WO 2008042982 A2 **[0006] [0007]**