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

(11) **EP 4 563 713 A1**

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

(43) Date of publication:
04.06.2025 Bulletin 2025/23

(21) Application number: **23846140.4**

(22) Date of filing: **03.07.2023**

(51) International Patent Classification (IPC):
C22C 38/00 *(2006.01)* ***C22C 38/24*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
C22C 38/00; C22C 38/24

(86) International application number:
PCT/JP2023/024603

(87) International publication number:
WO 2024/024407 (01.02.2024 Gazette 2024/05)

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

(30) Priority: **26.07.2022 JP 2022118915**

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(54) **ALLOY STEEL**

(57) Provided is an alloy steel capable of reducing the maximum crystal grain size and reducing the variability of the crystal grain size after an M50-equivalent alloy is quenched. This alloy steel is formed of, in mass%, 0.70-0.95% of C, 0.05-0.35% of Si, 0.05-0.45% of Mn, 3.90-4.35% of Cr, 3.90-4.60% of one or more of Mo and W according to a relational formula of (Mo+W/2), and 0.80-1.20% of V, the remaining portion being Fe and unavoidable impurities. In addition, Al and N are contained so as to satisfy condition (1) and condition (2). Condition (1) stipulates that the amount of Al is 0.02% or more or that the amount of N is 0.005% or more, in mass%. Condition (2) stipulates that $7.5<-\ln([Al]\%\times[N]\%)<11.5$ is satisfied.

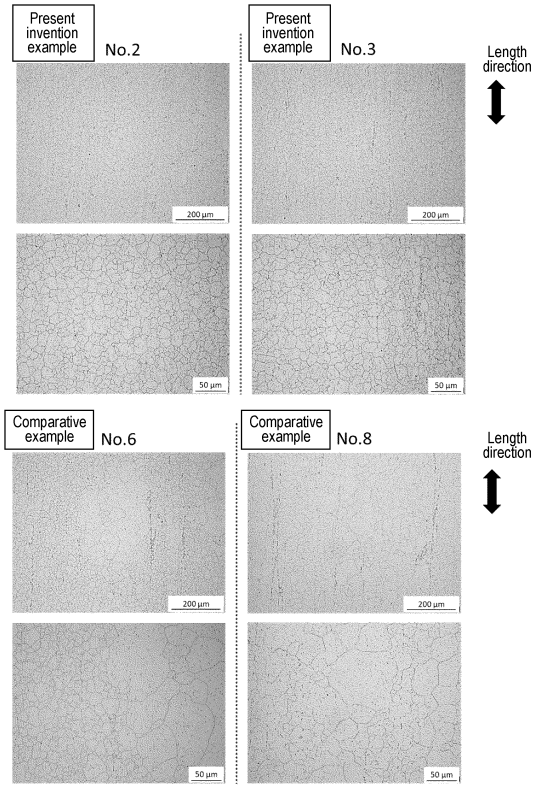


FIG. 1

EP 4 563 713 A1

Description

Technical Field

[0001] The present invention relates to an alloy steel.

Description of Related Art

[0002] The alloy specified in AMS6491 is called M50, and the composition thereof is a steel containing, in mass%, C (carbon): 0.80 to 0.85%, Mn (manganese): 0.15 to 0.35%, Cr (chromium): 4.00 to 4.25%, Mo (molybdenum): 4.00 to 4.50%, V (vanadium): 0.90 to 1.10%, with the remaining portion being Fe (iron) and impurities. The M50 is quenched and tempered, and is used as a bearing steel, for example, as engine parts for aircraft.

[0003] For example, Patent Literature 1 describes a manufacturing method for bearing steel characterized by nitriding a steel composed of, in weight ratio, C: 0.60 to 1.50%, Si: 0.15 to 1.00%, Mn: 0.15 to 0.50%, Cr: 3.0 to 19.0%, Mo: 0.50 to 6.50%, V: 0.05 to 1.50%, Al: 0.020 to 1.50%, with the remaining portion being Fe and unavoidable impurities, at a temperature of 500 to 600°C. The Patent Literature 1 also discloses that the addition of V is effective for crystal grain refinement and that it is effective to set the quenching temperature to 1200°C or lower.

Related Art

Patent Literature

[0004] Patent Literature 1 Japanese Patent Application Laid-Open No. 5-179401

SUMMARY

Technical Problem

[0005] One of the factors that reduce the mechanical properties of the M50 products mentioned above is the coarsening of crystal grains. In particular, even if the average crystal grain size is small, in cases where crystal grains are partially coarsened, resulting in a mixed grain structure in which coarse grains and fine grains coexist, there is concern about crack initiation originating from the coarse grain portion. Therefore, it is important to also reduce the maximum crystal grain size. The aforementioned patent literature does not consider reducing such maximum crystal grain size.

[0006] Therefore, the objective of the present invention is to provide an alloy steel capable of reducing the maximum crystal grain size after quenching of an M50 equivalent alloy and suppressing variation in the crystal grain size.

Solution to the Problem

[0007] The present invention has been made in consideration of the above-mentioned issues.

[0008] In other words, the present invention is an alloy steel consisting of, in mass%, C: 0.70 to 0.95%, Si: 0.05 to 0.35%, Mn: 0.05 to 0.45%, Cr: 3.90 to 4.35%, one or both of Mo and W according to a relational formula (Mo+W/2): 3.90 to 4.60%, V: 0.80 to 1.20%, with the remaining portion being Fe and unavoidable impurities, and further including Al and N to satisfy the following condition (1) and condition (2). Here, condition (1) is Al: 0.02% or more, or N: 0.005% or more in mass%, and condition (2) is $7.5<-\ln([Al]\%\times[N]\%)<11.5$.

[0009] Preferably, the maximum crystal grain size number according to ASTM-E930 is 6.0 or more.

[0010] Preferably, the average crystal grain size number according to ASTM-E112 is 8.0 or more. Effects

[0011] According to the present invention, the maximum crystal grain size after quenching of an M50 equivalent alloy may be reduced and variation in the crystal grain size may be suppressed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 shows cross-sectional photographs of samples after quenching of present invention examples and comparative examples.

DESCRIPTION OF EMBODIMENTS

[0013] First, the reasons for limiting the component composition of an alloy steel (M50 equivalent alloy) specified in the present invention are described.

C: 0.70 to 0.95 mass% (hereinafter also simply referred to as "%"),
C is an element effective for improving hardness, and a minimum of 0.70% is required. However, addition of C exceeding 0.95% reduces toughness, so C is set to 0.70% to 0.95%, preferably 0.80% or more, and also preferably 0.85% or less.

Si: 0.05 to 0.35%,

[0014] Si is used as a deoxidizing agent during steelmaking and is an effective element for improving machinability. When Si is less than 0.05%, the ductility of the material becomes too high, hindering cold machinability. On the other hand, addition of Si exceeding 0.35% reduces toughness, so Si is set to 0.05% to 0.35%, preferably 0.10% or more, and also preferably 0.25% or less.

Mn: 0.05 to 0.45%,

[0015] Mn is used as a deoxidizing agent and desulfurizing agent during steelmaking and is an effective element for improving hardenability, requiring a minimum of 0.05%. On the other hand, when Mn exceeds 0.45%, issues occur such as excessive increase in hardness, which deteriorates machinability. Therefore, Mn is set to 0.05% to 0.45%, preferably 0.15% or more, and also preferably 0.35% or less.

Cr: 3.90 to 4.35%,

[0016] Cr, like Mo described later, has the effect of improving hardenability and tempering softening resistance at high temperatures, so a minimum addition of 3.90% is needed. On the other hand, when Cr exceeds 4.35%, carbide precipitation is promoted, making it difficult to control hardness during manufacturing. Therefore, Cr is set to 3.90% to 4.35%, preferably 4.00% or more, and also preferably 4.25% or less.

[0017] According to the relational formula (Mo+W/2), one or both of Mo and W: 3.90 to 4.60%, Mo and W have similar effects, and are specified by (Mo+W/2) due to the atomic weight relationship thereof. A minimum addition of 3.90% is needed because Mo and W have the effect of improving hardenability and tempering softening resistance at high temperatures. On the other hand, when exceeding 4.60%, carbide precipitation is promoted, making it difficult to control hardness during manufacturing. Therefore, (Mo+W/2) is set to 3.90% to 4.60%, preferably 4.00% or more, and also preferably 4.50% or less.

[0018] In addition, following the component composition of the M50 equivalent alloy, all of the content of W can be replaced with the content of Mo. In this case, Mo becomes 3.90 to 4.60%, and is preferably 4.00% or more, and also preferably 4.50% or less. W can be included as an impurity, and for example, following the component composition of the M50 equivalent alloy, 0.25% or less of W can be included.

V: 0.80 to 1.20%,

[0019] V has the effect of improving tempering softening resistance and refining crystal grains. When V is less than 0.80%, MC carbide precipitation is low, and crystal grains become coarse. On the other hand, when V exceeds 1.20%, carbide precipitation is promoted, making it difficult to control hardness during manufacturing. Therefore, V is set to 0.80% to 1.20%, preferably 0.90% or more, and also preferably 1.10% or less.

[0020] The alloy steel of the present invention is further characterized in that Al and N are included to satisfy the following condition (1) and condition (2). Here, condition (1) is Al: 0.02% or more, or N: 0.005% or more in mass%, and condition (2) is $7.5<-\ln([Al]\%\times[N]\%)<11.5$. Al is used as a deoxidizing agent, and N is an element that can remain as an impurity. By allowing Al and N to exist in a solid solution state in the matrix, Al acts as a nucleus during MC carbide precipitation, which is effective for crystal grain refinement, and N has the effect of finely and uniformly dispersing MC carbides by dissolving into carbides and increasing the amount of MC carbides. Therefore, the alloy steel of the present invention contains 0.02% or more of Al, or 0.005% or more of N. Here, in the steel of the present invention, Al may be 0.02% or more and N may be 0.005% or more.

[0021] In the present invention, to obtain the effect of Al or N in solid solution as described above, it is effective to adjust the "solubility product" indicated by the product of the content (mass%) of Al and the content (mass%) of N. In other words, when $-\ln([Al]\%\times[N]\%)$ becomes less than 7.5, a large amount of AlN is formed, partially filling the precipitation sites of MC carbides. And because the amount of Al or N in solid solution also decreases at the AlN formation sites, the distribution of MC carbides remaining during quenching becomes nonuniform, causing coarsening of crystal grains. On the other hand, when $-\ln([Al]\%\times[N]\%)$ exceeds 11.5, although the formation of AlN can be suppressed, the effect of Al or N in solid solution does not become apparent due to the small amount of Al and N in solid solution. Therefore, $7.5<-\ln([Al]\%\times[N]\%)<11.5$ is set. The preferable lower limit of $-\ln([Al]\%\times[N]\%)$ is 8.0, more preferably 8.5, and even more preferably 9.0. Also, the

preferable upper limit of - ln([Al]%×[N]%) is 11.0, more preferably 10.5, and even more preferably 10.0.

[0022] Other than the elements described above, the rest consists of Fe and unavoidable impurities. Unavoidable impurities include P, S, Ni, Co, Cu, and O, and for example, following the component composition of the M50 equivalent alloy, the upper limits can be set as follows in mass%: P≤0.015%, S≤0.008%, Ni≤0.15%, Co≤0.25%, Cu≤0.10%, and O≤0.0030%.

[0023] The alloy steel of the present invention having the above-mentioned alloy component range is expected to consistently obtain good mechanical properties because the alloy steel has a small maximum crystal grain size (large maximum crystal grain size number) and small variation in the crystal grain size. The preferable maximum crystal grain size number (in accordance with ASTM-E930) of the present invention is 6.0 or more. Also, the preferable average crystal grain size number (in accordance with ASTM-E112) of the present invention is 8.0 or more. The more preferable lower limit of the average crystal grain size number is 8.5, and the even more preferable lower limit of the average crystal grain size number is 9.0. The crystal grain size numbers can be measured in the state after quenching or after quenching and tempering. This is because the crystal grain size does not substantially change between after quenching and after quenching and tempering.

Example

[0024] Steel ingots of 10 kg of the M50 equivalent alloy having the component composition shown in Table 1 were melted to obtain steels No. 1 to No. 5 as present invention examples and steel ingots No. 6 to No. 8 as comparative examples. Subsequently, hot working was performed to obtain 30 mm square bar experimental materials.

[Table 1]

Sample No.	Chemical composition (mass %)									-ln ([Al]%×[N]%)	Remark
	C	Si	Mn	Cr	Mo	V	Al	N	Fe		
No.1	0.81	0.17	0.26	4.17	4.36	0.94	0.260	0.0007	Bal.	8.61	Present invention example
No.2	0.76	0.19	0.26	4.22	4.37	0.95	0.014	0.0082	Bal.	9.07	
No.3	0.77	0.19	0.26	4.17	4.33	0.94	0.080	0.0009	Bal.	9.54	
No.4	0.85	0.22	0.25	4.22	4.49	1.01	0.042	0.0014	Bal.	9.74	
No.5	0.84	0.22	0.24	4.16	4.41	1.02	0.021	0.0015	Bal.	10.37	
No.6	0.80	0.17	0.26	4.21	4.41	0.95	0.220	0.0067	Bal.	6.52	Comparative example
No.7	0.77	0.19	0.26	4.17	4.24	0.93	0.012	0.0026	Bal.	10.38	
No.8	0.84	0.22	0.25	4.22	4.52	1.02	0.003	0.0015	Bal.	12.31	

[0025] To confirm the crystal grain size after quenching, test pieces were taken from the experimental materials of the present invention examples and the comparative examples obtained above after annealing treatment. Regarding the sampling location of the test pieces, the position was set at W/4-T/4 (W: length in the width direction, T: length in the thickness direction) of the 30 mm square cross section, and L/2 (L: length in the length direction) in the length direction. Subsequently, each of the materials was subjected to quenching treatment at 1115°C, and the crystal grain size was measured using an optical microscope according to ASTM standards (average crystal grain size according to ASTM-E112-13(2021), maximum crystal grain size according to ASTM-E930-18). The results are shown in Table 2. For No. 6, which had a mixed grain structure and the average crystal grain size could not be measured, the distribution ratio of crystal grain sizes is shown. From Table 1, it can be confirmed that the present invention examples satisfying Al: 0.020% or more, or N: 0.005% or more in mass%, and 7.5<-ln([Al]%×[N]%)<11.5, have an average crystal grain size at the same level as the comparative examples No. 7 and No. 8, but the maximum crystal grain size is refined to 6.0 or more in the crystal grain size number compared to the comparative examples, and the variation in the crystal grain size is small.

[0026] FIG. 1 also shows optical microscope photographs for No. 2, No. 3, No. 6, and No. 8. The observation position was set as the longitudinal cross section (T-L cross section parallel to the length direction and halved) of the test piece after quenching. The observation magnification in the upper row of FIG. 1 is 200 times, and the observation magnification in the lower row is 500 times. In the present invention examples (No. 2 and No. 3) satisfying condition (1) and condition (2) of the present invention, the crystal grain size is generally fine with small variation, while in the comparative examples (No. 6 and No. 8), coarse grains exceeding 50 μm can be observed among fine grains, and large variation in the crystal grain size can be confirmed from FIG. 1. From the above results, the variation in the crystal grain size after quenching of the M50 equivalent alloy may be suppressed by controlling the Al and N content as specified in the present invention. By tempering

the M50 equivalent alloy after quenching, M50 equivalent alloy products with suppressed deterioration of mechanical properties can be provided.

[Table 2]

Sample No.	Average crystal grain size No.	Maximum crystal grain size No.	Al content (mass%)	N content (mass%)	-ln ([Al]%×[N]%)	Remark
No.1	9.5	6.5	0.260	0.0007	8.61	Present invention example
No.2	9.5	7.0	0.014	0.0082	9.07	
No.3	9.5	7.0	0.080	0.0009	9.54	
No.4	9.0	6.5	0.042	0.0014	9.74	
No.5	9.5	6.0	0.021	0.0015	10.37	
No.6	3.0 (40%) 9.0 (60%)	1.0	0.220	0.0067	6.52	Comparative example
No.7	9.5	5.5	0.012	0.0026	10.38	
No.8	8.5	3.5	0.003	0.0015	12.31	

Claims

1. An alloy steel, comprising:

in mass%, C: 0.70 to 0.95%,
Si: 0.05 to 0.35%,
Mn: 0.05 to 0.45%,
Cr: 3.90 to 4.35%,
according to a relational formula (Mo+W/2), one or both of Mo and W: 3.90 to 4.60%,
V: 0.80 to 1.20%, and
a remaining portion: Fe and unavoidable impurities, and
further comprising Al and N to satisfy the following condition (1) and condition (2),
condition (1): Al: 0.02 mass% or more, or N: 0.005 mass% or more, and
condition (2): $7.5 < -\ln([Al]\% \times [N]\%) < 11.5$.

2. The alloy steel according to claim 1, wherein a maximum crystal grain size number in accordance with ASTM-E930 is 6.0 or more.

3. The alloy steel according to claim 2, wherein an average crystal grain size number in accordance with ASTM-E112 is 8.0 or more.

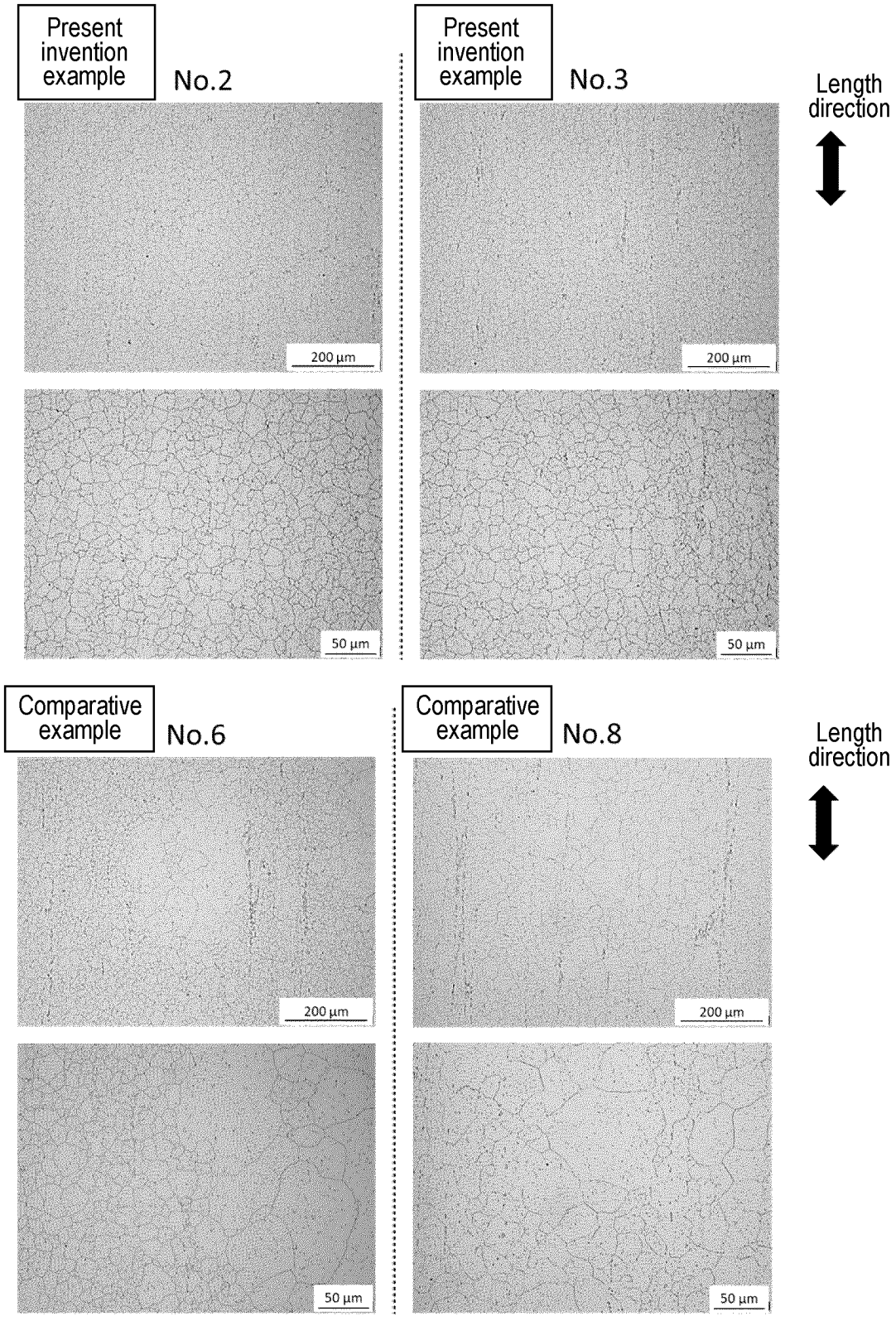

Present invention example
No.2
Present invention example
No.3
Length direction
200 µm
200 µm
50 µm
50 µm
Comparative example
No.6
Comparative example
No.8
Length direction
200 µm
200 µm
50 µm
50 µm

FIG. 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/024603

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***C22C 38/24***(2006.01)i
FI: C22C38/00 301Z; C22C38/00 302Z; C22C38/24

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; C22C38/24

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.
X	JP 55-145158 A (DAIDO STEEL CO LTD) 12 November 1980 (1980-11-12) tables 1-2	1-3
X	JP 6-322482 A (HITACHI METALS LTD) 22 November 1994 (1994-11-22) paragraph [0027], table 1	1-3
A	JP 2019-522109 A (OVAKO SWEDEN AB) 08 August 2019 (2019-08-08) paragraph [0048], fig. 4	1-3
A	JP 61-217559 A (DAIDO STEEL CO LTD) 27 September 1986 (1986-09-27) entire text	1-3

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 September 2023	**19 September 2023**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/024603

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 55-145158 A	12 November 1980	(Family: none)	
JP 6-322482 A	22 November 1994	US 5651842 A p. 7, left column, lines 20-29, tables 1 EP 0630984 A1	
JP 2019-522109 A	08 August 2019	US 2019/0127815 A1 paragraph [0054], fig. 4 WO 2017/207651 A1 EP 3464669 A1 KR 10-2019-0031446 A CN 109642299 A	
JP 61-217559 A	27 September 1986	(Family: none)	

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 5179401 A **[0004]**