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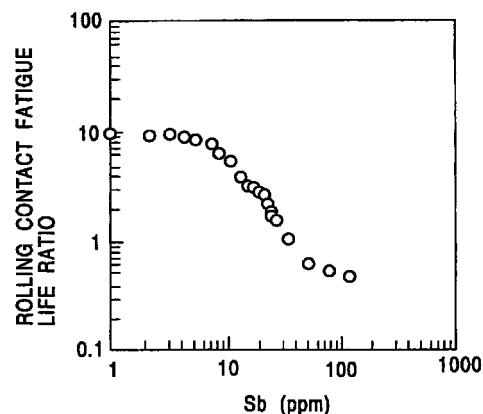
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(54) **BEARING STEEL EXCELLENT IN ROLLING FATIGUE LIFE**

(57) The present invention relates to a bearing steel which is used as a component for rolling bearings, such as roller bearings and ball bearings, and more particularly, which is used as a component for bearings having superior rolling contact fatigue life. That is, the bearing steel having superior rolling contact fatigue life contains 0.95 to 1.10 mass% of C, more than 1.60 to 3.50 mass% of Cr, 0.0015 mass% or less of O, 0.0010 mass% or less of Sb, and the balance being Fe and incidental impurities. Alternatively, the bearing steel may further contain at least one element selected from the group consisting of 2.5 mass% or less of Si, 2.5 mass% or less of Mn, 2.5 mass% or less of Mo, 3.0 mass% or less of Ni, 1.5 mass% or less of Nb, 1.5 mass% or less of V, 2.0 mass% or less of Cu, and 0.08 mass% or less of Al.

FIGURE 1



Description

Technical Field

5 **[0001]** The present invention relates to bearing steels which are used as components for rolling bearings, such as roller bearings and ball bearings. More particularly, the invention relates to a bearing steel used as a component for bearings having superior rolling contact fatigue life.

Background Art

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[0002] Bearing steels used for rolling bearings and the like are required to have a long rolling contact fatigue life. It is well known that, in general, hard oxide non-metallic inclusions in the steel adversely affect the rolling contact fatigue life of the bearing.

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[0003] Accordingly, in order to improve the rolling contact fatigue life by reducing the amount of such non-metallic inclusions, conventionally, efforts have been made to mainly reduce the oxygen content in the steel. With the advancement of steelmaking techniques, in a steel to which Si or Al is added as a deoxidizing agent, the oxygen content in the steel has been decreased to 0.0010 mass% or less. As a result, the amount of the hard oxide non-metallic inclusions in the steel has been greatly reduced, resulting in improvement in rolling contact fatigue life.

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[0004] However, the improvement in rolling contact fatigue life by the reduction of oxygen has already reached the limit.

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[0005] Recently, there have been tendencies to aim at further improvement in rolling contact fatigue life. For example, Japanese Unexamined Patent Application Publication No. 3-126839 discloses a method of adjusting the number of oxide non-metallic inclusions per unit area or per unit volume, namely, a method of adjusting the distribution thereof. Japanese Unexamined Patent Application Publication No. 5-25587 discloses a method of adjusting the predicted maximum diameter of the oxide non-metallic inclusions calculated based on statistics of extreme value, namely, a method of adjusting the shape thereof. In either case, the influence of the oxide non-metallic inclusions is reduced by adjusting the distribution or shape of the oxide non-metallic inclusions, not by adjusting the amount thereof.

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[0006] However, in order to reduce the number of the oxide non-metallic inclusions per unit area or the maximum diameter in accordance with the known techniques, further improvement in steelmaking facilities or modification of the manufacturing process is required. Therefore, in order to realize the above, a large amount of money is required to be invested, and thus manufacturing cost inevitably increases. In addition, in order to secure the rolling contact fatigue life, detailed characterization of the non-metallic inclusions is required, and thus productivity inevitably decreases.

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[0007] On the other hand, methods of improving rolling contact fatigue life by reducing impurities are disclosed in Japanese Unexamined Patent Application Publication Nos. 10-68047, 10-158790, 10-168547, and so on. Japanese Unexamined Patent Application Publication No. 9-291340 (PCT/JP97/00549) also discloses a method of controlling sulfide non-metallic inclusions which are hard non-metallic inclusions other than the oxide non-metallic inclusions. In either case, a trigger material for fatigue fracture is aimed to be reduced. However, since either method is targeted at steels to which Si or Al is added as a deoxidizing agent, silicon oxide or aluminum oxide is unavoidably formed, and the rolling contact fatigue life fluctuates, and also the improvement thereof is limited.

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[0008] Accordingly, it is a primary object of the present invention to provide a bearing steel which can be manufactured by merely adjusting the composition, thus being advantageous in view of productivity, and which has superior rolling contact fatigue life.

Disclosure of Invention

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[0009] The present invention has been carried out to achieve the object described above. Owing to recent steel-making techniques, when approximately 1 mass% of C is incorporated, it is possible to reduce the O content to approximately 0.0010 mass% even without adding Si or Al as the deoxidizing agent. The improvement in hardenability and in rolling contact fatigue life can be achieved by the addition of a large amount of Cr instead of by the addition of Si or Al. Accordingly, the present inventors have carried out researches on the influences of impurity elements, using a material which contains approximately 1 mass% of C and a large amount of Cr, and does not contain Si or Al, in which the O content is reduced to approximately 10 ppm. As a result, it has been found that Sb which is mixed into the steel as the impurity element adversely affects the rolling contact fatigue life.

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[0010] The rolling contact fatigue life was investigated using a specimen which contains 0.98 to 1.05 mass% of C, 1.65 to 3.45 mass% of Cr, 0.0008 to 0.0012 mass% of O, 0.0001 to 0.0100 mass% of Sb, and the balance being substantially Fe. The number of oxide non-metallic inclusions was 100 to 200 pieces/320 mm², and the maximum diameter thereof was 8 to 12 μm in an observation area of 320 mm². FIG. 1 shows the influence of the Sb content in steel on the rolling contact fatigue life. When the Sb content in the steel was decreased to 0.0015 mass% or less, the rolling contact

fatigue life improved. At approximately 0.0010 mass%, the improvement effect was saturated. Although the reason for such a phenomenon is not always clear, when the Sb content in steel exceeds a certain limit, excessive Sb is believed to segregate in grain boundaries, thus promoting fatigue cracks propagation and accelerating the occurrence of fracture.

5 **[0011]** The present invention has been achieved based on the knowledge described above.

[0012] A bearing steel having superior rolling contact fatigue life, in accordance with the present invention, contains 0.95 to 1.10 mass% of C, more than 1.60 to 3.50 mass% of Cr, 0.0015 mass% or less of O, 0.0010 mass% or less of Sb, and the balance being Fe and incidental impurities. Alternatively, the bearing steel may further contain at least one element selected from the group consisting of 2.5 mass% or less of Si, 2.5 mass% or less of Mn, 2.5 mass% or less of Mo, 3.0 mass% or less of Ni, 1.5 mass% or less of Nb, 1.5 mass% or less of V, 2.0 mass% or less of Cu, and 0.08 mass% or less of Al.

[0013] The reasons for specifying the limits in the composition in accordance with the present invention will be described.

15 C: 0.95 to 1.10 mass%

[0014] Carbon is an element that dissolves in the matrix and effectively strengthens martensite. Carbon is incorporated in order to secure strength after quenching and tempering and to improve rolling contact fatigue life. If the carbon content is less than 0.95 mass%, the above effects are not achieved. If the carbon content exceeds 1.10 mass%, giant carbides are formed in the casting process, resulting in a decrease in workability and in rolling contact fatigue life. Therefore, the carbon content is set in the range of 0.95% to 1.10 mass%.

Cr: more than 1.60 to 3.50 mass%

25 **[0015]** Chromium stabilizes carbides and makes the carbides remain after quenching, thus being effective in improving wear resistance. Chromium also improves hardenability and improves cold workability by promoting spheroidization of structure. If the chromium content is 1.60 mass% or less, the above effects are not achieved. If the chromium content exceeds 3.50 mass%, the amount of carbides remaining due to quenching increases. As a result, the amount of carbon dissolved in the matrix is decreased, resulting in a decrease in strength and in rolling contact fatigue life. Therefore, the chromium content is set in the range of more than 1.60% to 3.50 mass%, and preferably, in the range of more than 1.60 to 2.50 mass%.

O: 0.0015 mass% or less

35 **[0016]** Since oxygen forms hard oxide non-metallic inclusions and decreases rolling contact fatigue life, a small content is desirable. However, the content up to 0.0015 mass% is permissible. Therefore, the oxygen content is set in the range of 0.0015 mass% or less, and preferably, at 0.0010 mass% or less. Sb: 0.0010 mass% or less

[0017] Antimony is a particularly important element in the present invention. Antimony suppresses the formation of a decarburized layer and improves the productivity in heat treatment, which is advantageous. However, antimony decreases hot workability and toughness and significantly decreases rolling contact fatigue life. Therefore, the antimony content must be limited to 0.0010 mass% or less.

[0018] Furthermore, at least one element among the elements described below may be incorporated.

Si: 2.5 mass% or less

45 **[0019]** Silicon is an element that retards softening during tempering. Consequently, strength after quenching and tempering is increased and rolling contact fatigue life is improved. Silicon is an element that also acts as a deoxidizing agent in the melting process to reduce oxygen in the steel. However, if the amount of silicon added exceeds 2.5 mass%, workability and toughness are decreased. Therefore, the silicon content is set in the range of 2.5 mass% or less, and preferably, in the range of 0.15% to 2.0 mass%.

Mn: 2.5 mass% or less

55 **[0020]** Manganese is an element that improves the hardenability of steel. Consequently, manganese improves the toughness and strength of matrix martensite and improves rolling contact fatigue life. However, if the manganese content exceeds 2.5 mass%, machinability and toughness are decreased. Therefore, the manganese content is set in the range of 2.5 mass% or less, and preferably, in the range of 0.10 to 2.0 mass%.

Mo: 2.5 mass% or less

[0021] Molybdenum is an element that improves hardenability. Consequently, molybdenum improves strength as well as rolling contact fatigue life. However, if the amount of molybdenum added exceeds 2.5 mass%, carbides are stabilized. As a result, the strength is decreased and the rolling contact fatigue life is decreased. Molybdenum is also an expensive element. Therefore, the molybdenum content is set in the range of 2.5 mass% or less, and preferably, in the range of 0.10 to 1.5 mass%.

Ni: 3.0 mass% or less.

[0022] Nickel is an element that improves hardenability. Consequently, nickel improves strength as well as rolling contact fatigue life. However, the effects of addition in the amount exceeding 3.0 mass% are saturated. Nickel is also an expensive element. Therefore, in view of the effect gained and cost, the nickel content is set in the range of 3.0 mass% or less, and preferably, in the range of 0.10 to 2.0 mass%.

Nb: 1.5 mass% or less

[0023] Niobium is an element that improves hardenability. Consequently, niobium improves strength as well as rolling contact fatigue life. However, if the amount of niobium added exceeds 1.5 mass%, carbides are stabilized. As a result, the strength is decreased and the rolling contact fatigue life is decreased. Niobium is also an expensive element. Therefore, the niobium content is set in the range of 1.5 mass% or less, and preferably, in the range of 0.05 to 1.0 mass%.

V: 1.5 mass% or less

[0024] Vanadium is an element that improves hardenability. Consequently, vanadium improves strength as well as rolling contact fatigue life. However, if the amount of vanadium added exceeds 1.5 mass%, carbides are stabilized. As a result, the strength is decreased and the rolling contact fatigue life is decreased. Vanadium is also an expensive element. Therefore, the vanadium content is set at 1.5 mass% or less, and preferably, in the range of 0.05% to 1.0 mass%.

Cu: 2.0 mass% or less

[0025] Copper is an element that improves hardenability. Consequently, copper improves strength as well as rolling contact fatigue life. However, if the amount of copper added exceeds 2.0 mass%, forgeability is decreased. Therefore, the copper content is set in the range of 2.0 mass% or less, and preferably, in the range of 0.10 to 1.5 mass%.

Al: 0.08 mass% or less

[0026] Aluminum is an element that increases resistance to temper softening. Consequently, strength after quenching and tempering is increased and rolling contact fatigue life is improved. Aluminum is an element that also acts as a deoxidizing agent in the melting process to reduce oxygen in the steel. If the amount of silicon added exceeds 0.08 mass%, workability and toughness are decreased. Therefore, the aluminum content is set in the range of 0.08 mass% or less, and preferably, in the range of 0.005 to 0.05 mass%.

[0027] Although the elements described above constitute the present invention, as a more preferred embodiment, phosphorus, sulfur, titanium, and nitrogen, as impurity elements, are desirably restricted within the ranges described below.

P: 0.025 mass% or less

[0028] Phosphorus decreases the toughness and rolling contact fatigue life of the steel. Therefore, it is desirable that the phosphorus content be as low as possible. The permissible upper limit of the phosphorus content is set at 0.025 mass%, and preferably, at 0.015 mass%.

S: 0.025 mass% or less

[0029] Sulfur combines with manganese to form MnS and improves machinability. However, rolling contact fatigue life is decreased when a large amount of sulfur is incorporated. The permissible upper limit of the sulfur content is set at 0.025 mass%, and preferably, at 0.010 mass%.

Ti: 0.010 mass% or less

[0030] Titanium forms hard nitrides and decreases rolling contact fatigue life. Therefore, it is desirable that the titanium content be as low as possible. The permissible upper limit of the titanium content is set at 0.010 mass%, and preferably, at 0.005 mass%.

N: 0.015 mass% or less

[0031] Nitrogen forms hard nitrides and decreases rolling contact fatigue life. Therefore, it is desirable that the nitrogen content be as low as possible. The permissible upper limit of the nitrogen content is set at 0.015 mass%, and preferably, at 0.008 mass%.

Brief Description of the Drawings

[0032]

FIG. 1 is a graph which shows the influence of the Sb content on B_{10} life.

Best Mode for Carrying Out the Invention

[0033] Examples of the present invention will be described below. However, embodiments of the present invention are not limited to the examples.

[0034] Each of the steels having the chemical composition shown in Tables 1 and 2 were melted in a converter, and then a bloom having a size of 400×560 mm was produced by continuous casting. The bloom was subjected to soaking at $1,200^{\circ}\text{C}$ for 30 hours, and hot rolled to a steel bar with a diameter of 65 mm. The steel bar was subjected to normalizing at 860°C and spheroidizing annealing in the range of 760 to 800°C , and was maintained at 830°C for 30 minutes, followed by quenching, and then tempering was performed at 180°C for 2 hours. The tempered material was cut and lapped, and 12 specimens for a rolling contact fatigue test, which were shaped like a disk having a size of 60 mm in diameter by 5 mm thick, were obtained for each steel.

[0035] The rolling contact fatigue test was performed with a Mori thrust-type rolling contact fatigue tester under operating conditions of a maximum Hertzian contact stress of 5,260 MPa and a stress cycle frequency of 30 Hz, using #68 turbine oil as a lubricant oil. The test results were plotted onto a probability paper in accordance with a Weibull distribution, and the B_{10} life (the total number of load cycles which were repeatedly applied until flaking occurred at an accumulated failure probability of 10%) was obtained. Evaluation was performed based on the relative ratio to the life of Steel No. 1 (JIS steel type: SUJ2) as a conventional steel being set as 1.

[0036] The evaluation results are also shown in Tables 1 and 2. As is obvious from Tables 1 and 2, Steel No. 2 and Steel Nos. 6 to 25 of the present invention have excellent values of the B_{10} life ratio, which are 1.7 to 5.6 times that of the conventional steel (Steel No. 1).

[0037] In contrast, with respect to Steel Nos. 4 and 5 as comparative steels, C and O, respectively, are out of the ranges of the present invention, and the B_{10} life ratio is inferior to that of the conventional steel. Except for Sb, there is no great difference in chemical composition between Steel No. 3 as a comparative steel and Steel No. 2 of the present invention. Nevertheless, Steel No. 3 has a B_{10} life ratio of 1.1, which is inferior to the value 3.2 of Steel No. 2. Clearly, the effect of decreasing the Sb content is observable.

Table 1

No	Chemical composition of steel (mass%)																B ₁₀ life ratio (steel No.1:1)	Remarks
	C	Si	Mn	P	S	Cr	Mo	V	Nb	Ni	Cu	Al	Ti	Sb	N	O		
1	0.99	0.21	0.46	0.015	0.005	1.34	-	-	-	-	-	0.021	0.003	0.0030	0.0052	0.0009	1.0	Conventional steel
2	1.01	-	-	0.010	0.003	2.46	-	-	-	-	-	-	0.002	0.0008	0.0040	0.0007	3.2	Steel of present invention
3	1.00	-	-	0.015	0.004	2.43	-	-	-	-	-	-	0.004	0.0028	0.0042	0.0009	1.1	Comparative steel
4	0.40	-	-	0.015	0.005	2.20	-	-	-	-	-	-	0.005	0.0008	0.0042	0.0011	0.8	Comparative steel
5	1.02	-	-	0.013	0.008	2.21	-	-	-	-	-	-	0.005	0.0009	0.0055	0.0024	0.6	Comparative steel
6	1.02	-	-	0.012	0.004	1.68	-	-	-	-	-	-	0.003	0.0008	0.0044	0.0010	1.7	Steel of present invention
7	1.02	1.75	-	0.014	0.003	2.00	-	-	-	-	-	-	0.003	0.0008	0.0041	0.0008	4.6	Steel of present invention
8	1.06	-	1.87	0.009	0.004	2.04	-	-	-	-	-	-	0.004	0.0007	0.0037	0.0007	3.9	Steel of present invention
9	1.04	-	-	0.010	0.004	1.99	1.24	-	-	-	-	-	0.005	0.0007	0.0048	0.0009	4.6	Steel of present invention
10	1.03	-	-	0.010	0.003	1.96	-	0.83	-	-	-	-	0.003	0.0008	0.0038	0.0007	3.9	Steel of present invention
11	1.03	-	-	0.008	0.003	1.97	-	-	0.79	-	-	-	0.004	0.0008	0.0043	0.0008	3.2	Steel of present invention
12	1.00	-	-	0.013	0.008	2.02	-	-	-	1.96	-	-	0.003	0.0008	0.0041	0.0006	5.5	Steel of present invention
13	1.02	-	-	0.012	0.005	2.01	-	-	-	-	1.32	-	0.003	0.0007	0.0041	0.0008	4.6	Steel of present invention
14	1.00	-	-	0.011	0.004	2.01	-	-	-	-	-	0.047	0.002	0.0006	0.0036	0.0004	4.2	Steel of present invention
15	0.99	0.23	0.42	0.009	0.005	1.97	-	-	-	-	-	0.023	0.002	0.0008	0.0038	0.0006	3.1	Steel of present invention

Table 2

No	Chemical composition of steel (mass%)															B ₁₀ life ratio (steel No. 1:1)	Remarks	
	C	Si	Mn	P	S	Cr	Mo	V	Nb	Ni	Cu	Al	Ti	Sb	N			O
16	0.98	0.79	0.11	0.008	0.004	1.96	-	-	-	-	-	0.023	0.005	0.0008	0.0038	0.0006	3.4	Steel of present invention
17	1.03	0.12	1.44	0.011	0.003	1.96	-	-	-	-	-	0.025	0.002	0.0009	0.0042	0.0007	3.6	Steel of present invention
18	0.99	1.01	1.03	0.010	0.003	1.98	-	-	-	-	-	0.021	0.003	0.0007	0.0041	0.0008	3.9	Steel of present invention
19	1.05	1.02	0.47	0.010	0.004	2.01	0.47	-	-	-	-	0.022	0.002	0.0009	0.0038	0.0007	4.5	Steel of present invention
20	1.07	0.27	0.42	0.008	0.005	1.76	0.26	0.31	-	-	-	0.022	0.004	0.0007	0.0039	0.0007	4.4	Steel of present invention
21	1.01	0.27	0.48	0.012	0.002	1.79	-	-	0.25	-	-	0.028	0.002	0.0006	0.0040	0.0005	3.7	Steel of present invention
22	0.99	0.25	0.42	0.012	0.003	1.85	-	-	-	0.88	0.48	0.023	0.003	0.0007	0.0039	0.0006	4.2	Steel of present invention
23	1.00	0.26	0.38	0.010	0.005	1.82	0.49	-	-	0.79	0.37	0.025	0.004	0.0009	0.0042	0.0008	5.4	Steel of present invention
24	1.04	0.26	0.86	0.011	0.004	1.77	-	0.25	-	0.76	0.41	0.021	0.004	0.0007	0.0042	0.0007	4.3	Steel of present invention
25	0.97	0.24	0.42	0.009	0.005	1.64	0.43	0.21	0.18	0.51	0.28	0.024	0.004	0.0007	0.0038	0.0009	5.6	Steel of present invention

Industrial Applicability

[0038] According to the present invention, a bearing steel having significantly superior rolling contact fatigue life can be obtained by merely adjusting the composition, such as by adding a large amount of Cr, and in particular, by limiting the Sb content in the steel to 0.0010 mass% or less. The Sb content can be easily limited by controlling scraps, which is advantageous in view of productivity, and industrial contributions are great.

Claims

1. A bearing steel having superior rolling contact fatigue life comprising:

0.95 to 1.10 mass% of C;
more than 1.60 to 3.50 mass% of Cr;
0.0015 mass% or less of O;
0.0010 mass% or less of Sb; and
the balance being Fe and incidental impurities.

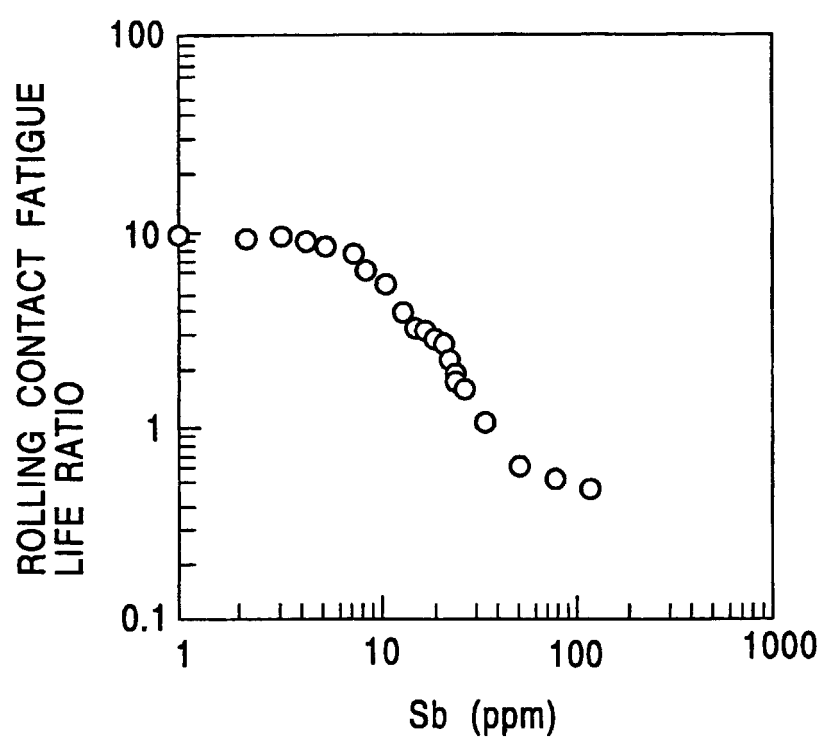
2. A bearing steel having superior rolling contact fatigue life comprising:

0.95 to 1.10 mass% of C;
more than 1.60 to 3.50 mass% of Cr;
0.0015 mass% or less of O;
0.0010 mass% or less of Sb;
at least one element selected from the group consisting of:

2.5 mass% or less of Si,
2.5 mass% or less of Mn,
2.5 mass% or less of Mo,
3.0 mass% or less of Ni,
1.5 mass% or less of Nb,
1.5 mass% or less of V,
2.0 mass% or less of Cu, and
0.08 mass% or less of Al; and

the balance being Fe and incidental impurities.

FIGURE 1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP99/05986

A. CLASSIFICATION OF SUBJECT MATTER
Itn.Cl⁷ C22C38/00

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)
Itn.Cl⁷ C22C38/00-38/60Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1926-1996 Toroku Jitsuyo Shinan Koho 1994-2000
Kokai Jitsuyo Shinan Koho 1971-2000 Jitsuyo Shinan Toroku Koho 1996-2000Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPI
JICST
ICIREPAT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP, 8-92689, A (Kawasaki Steel Corporation), 09 April, 1996 (09.04.96) (Family: none)	1, 2
A	JP, 6-287693, A (Kawasaki Steel Corporation), 11 October, 1994 (11.10.94) (Family: none)	1, 2
A	JP, 6-271982, A (Kawasaki Steel Corporation), 27 September, 1994 (27.09.94) (Family: none)	1, 2
A	JP, 10-158790, A (Kawasaki Steel Corporation), 16 June, 1998 (16.06.98) (Family: none)	1, 2

☐ 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
25 January, 2000 (25.01.00)Date of mailing of the international search report
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