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(54) **HIGH-STRENGTH COLD-ROLLED STEEL SHEET EXCELLENT IN WELDABILITY AND PROCESS FOR PRODUCTION OF SAME**

(57) A high strength cold rolled steel sheet with excellent weldability in which humping bead is not formed by performing plasma welding at high speed and that has a TS of 440 MPa or more, which does not deteriorate the formability of a tailor-welded-blank, and a method for manufacturing the high strength cold rolled steel sheet are provided. The high strength cold rolled steel sheet that is excellent in weldability and has a TS of 440 MPa or more includes a composition including C: 0.0005 to 0.005%, Si: 0.1 to 1.0%, Mn: 1 to 2.5%, P: 0.01 to 0.2%, S: 0.015% or less, sol. Al: 0.05% or less, N: 0.007% or less, Ti: 0.01 to 0.1%, B: 0.0005 to 0.0020%, Cu: 0.05 to 0.5%, and Ni: 0.03 to 0.5% by mass with the balance Fe and incidental impurities; and a microstructure constituted by a ferrite single phase.

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Description

Technical Field

[0001] The present invention relates to a high strength cold rolled steel sheet with formability and weldability that is suitably used for structures such as railway vehicles, automobiles, and ships. In particular, the present invention relates to a high strength cold rolled steel sheet having a tensile strength TS of 440 MPa or more and a method for manufacturing the same.

Background Art

[0002] With the progress of degassing technologies in a steelmaking process, it has been possible to manufacture a large amount of ultra low carbon steel whose C amount is reduced to 0.0030% or less by mass at relatively low costs. An interstitial free (IF) cold rolled steel sheet with excellent formability made by adding a carbonitride-forming element such as Ti or Nb to ultra low carbon steel has been widely used for automobile components, electric device components, and the like. Thus, various IF cold rolled steel sheets have been developed. For example, Patent Documents 1 and 2 disclose cold rolled steel sheets with excellent formability. In the cold rolled steel sheets, resistance to cold-work embrittlement is improved by further adding B to the IF steel to which Ti or Nb is added. Patent Document 3 discloses a deep-drawing steel sheet with excellent brazing property obtained by further adding Ni to the IF steel to which Ti or Nb is added.

[0003] In recent years, an automotive steel sheet having higher strength has been developed in terms of weight reduction of a car body and crash safety of automobiles. Furthermore, a tailor-welded-blank made by combining two or more steel sheets having different thicknesses and characteristics through welding has been used as an automotive steel sheet to reduce the numbers of steps and dies. Therefore, there has been a growing demand for a high strength steel sheet with excellent formability and weldability, particularly a high strength cold rolled steel sheet having a TS of 440 MPa or more.

[0004] The IF cold rolled steel sheet described above is desired in consideration of formability. However, the weldability of a tailor-welded-blank that uses an IF cold rolled steel sheet has hardly been investigated. Regarding the weldability of a tailor-welded-blank, Patent Document 4 discloses a method for manufacturing a tailor-welded-blank by welding steel sheets having different thicknesses through plasma welding that is performed with low equipment cost, at high speed, and without using a welding metal. In that method, a weld defect called humping bead is prevented by adjusting the C amount of the thicker steel sheet to 0.1% or more by mass or by adjusting the Si amount to 0.8% or more by mass.

Related Art Documents

[0005]

Patent Document 1: Japanese Unexamined Patent Application Publication No. 61-246344
Patent Document 2: Japanese Unexamined Patent Application Publication No. 1-149943
Patent Document 3: Japanese Unexamined Patent Application Publication No. 2-232342
Patent Document 4: Japanese Unexamined Patent Application Publication No. 2003-94170

Disclosure of Invention

Problems to be Solved by the Invention

[0006] However, in the method for manufacturing a tailor-welded-blank described in Patent Document 4, the C amount of at least one of the steel sheets needs to be adjusted to 0.1% or more by mass or the Si amount needs to be adjusted to 0.8% or more by mass. This poses a problem in that the formability of the tailor-welded-blank is significantly deteriorated.

[0007] In addition, high speed plasma arc welding easily causes the formation of humping bead. This poses a problem of high speed welding, that is, difficulty in improving productivity. To solve the problems, an object of the present invention is to achieve high speed welding by improving a steel sheet.

[0008] In other words, an object of the present invention is to provide a high strength cold rolled steel sheet with excellent weldability in which humping bead is not formed by performing plasma welding at high speed and that has a TS of 440 MPa or more, which does not deteriorate the formability of a tailor-welded-blank. Another object of the present invention is to provide a method for manufacturing the high strength cold rolled steel sheet.

Means for Solving the Problems

[0009] The inventors of the present invention discovered the following findings after their investigation about the formability and weldability of a high strength cold rolled steel sheet in which humping bead is not formed by performing plasma welding at high speed and that has a TS of 440 MPa or more, which does not deteriorate the formability of a tailor-welded-blank.

i) The formation of humping bead during high speed plasma welding can be suppressed by adding Cu to IF steel, and further prevented by controlling the O amount in the steel within a proper range.
ii) Excellent formability of a tailor-welded-blank is achieved by adjusting the C amount to 0.005% or less by mass, by using IF steel to which Ti is added, and by using a microstructure constituted by a ferrite single phase.

[0010] Accordingly, the present invention provides a high strength cold rolled steel sheet that is excellent in weldability and has a TS of 440 MPa or more, including a composition including C: 0.0005 to 0.005%, Si: 0.1 to 1.0%, Mn: 1 to 2.5%, P: 0.01 to 0.2%, S: 0.015% or less, sol. Al: 0.05% or less, N: 0.007% or less, Ti: 0.01 to 0.1%, B: 0.0005 to 0.0020%, Cu: 0.05 to 0.5%, and Ni: 0.03 to 0.5% by mass with the balance Fe and incidental impurities; and a microstructure constituted by a ferrite single phase.
[0011] In the high strength cold rolled steel sheet of the present invention, the composition preferably further includes 0: 0.0025 to 0.0080% by mass or at least one of Se: 0.0005 to 0.01% and Te: 0.0005 to 0.01% by mass.
[0012] The high strength cold rolled steel sheet of the present invention can be manufactured by a method including the steps of hot-rolling a slab having the composition described above, coiling at a coiling temperature of 680˚C or less, pickling, cold-rolling at a reduction ratio of 40% or more, and performing recrystallization annealing at 700 to 850˚C.

Advantages

[0013] According to the present invention, a high strength cold rolled steel sheet with excellent weldability in which humping bead is not formed by performing plasma welding at high speed and that has a TS of 440 MPa or more, which does not deteriorate the formability of a tailor-welded-blank can be manufactured. Furthermore, the high strength cold rolled steel sheet of the present invention with excellent formability is suitably used for not only automobile components but also electric device components and the like.

Best Mode for Carrying Out the Invention

[0014] The present invention will now be described in detail. Herein, % denotes the amount of elements expressed as percent by mass unless specified.

1) Composition

C: 0.0005 to 0.005%

[0015] When the C amount is less than 0.0005%, a heavy burden is placed on decarbonization refining at a steelmaking stage, which increases the costs due to, for example, vacuum degassing. When the C amount is more than 0.005%, the formability is deteriorated. Thus, the C amount is in the range of 0.0005 to 0.005%, and is preferably 0.003% or less.

Si: 0.1 to 1.0%

[0016] Si is an element that is effective for imparting higher strength to steel. To achieve such an effect, the Si amount needs to be 0.1% or more. However, a Si amount of more than 1.0% causes embrittlement of ferrite, which impairs the strength-ductility balance. Thus, the Si amount is in the range of 0.1 to 1.0%, and is preferably 0.7% or less.

Mn: 1 to 2.5%

[0017] Mn is an element that is effective for imparting higher strength to steel. To achieve such an effect, the Mn amount needs to be 1% or more. However, a Mn amount of more than 2.5% facilitates centerline segregation in a slab and deteriorates the formability of end products. Thus, the Mn amount is in the range of 1 to 2.5%. To prevent hot brittleness due to FeS formation, Mn is combined with solid solution S in the steel to form MnS. In this case, assuming that the Mn amount is [Mn] and the S amount is [S], it is preferable to satisfy $([Mn]/55)/([S]/32) > 100$.

P: 0.01 to 0.2%

[0018] P is an element that is effective for imparting higher strength to steel. To achieve such an effect, the P amount needs to be 0.01% or more. However, a P amount of more than 0.2% not only may cause grain boundary fracture in an HAZ or deteriorates low temperature toughness of a base metal or a welded portion, but also deteriorates an anti-crash property due to grain boundary segregation. Thus, the P amount is in the range of 0.01 to 0.2%.

S: 0.015% or less

[0019] A S amount of more than 0.015% deteriorates low temperature toughness of a base metal or a welded portion as with P. Thus, the S amount is 0.015% or less, and a smaller amount is preferable. As described above, it is preferable to satisfy ([Mn]/55)/([S]/32) > 100.

sol. Al: 0.05% or less

[0020] Al is normally used as a deoxidizing element at a steelmaking stage. Since the 0 amount is controlled within a specific range in the present invention, the sol. Al amount is 0.05% or less. A sol. Al amount of more than 0.05% is not preferable because the formability is deteriorated due to a large amount of Al_2O_3 and inclusions may cause weld cracking. Thus, the sol. Al amount is 0.05% or less.

N: 0.007% or less

[0021] A N amount of more than 0.007% deteriorates the formability and anti-aging property. Thus, the N amount is 0.007% or less, and a smaller amount is preferable.

Ti: 0.01 to 0.1%

[0022] Ti improves the formability and anti-aging property by forming a precipitate with C or N. To achieve such an effect, the Ti amount needs to be 0.01% or more. However, a Ti amount of more than 0.1% increases an alloy cost. Thus, the Ti amount is in the range of 0.01 to 0.1%. To effectively produce the effect of B described below, assuming that the Ti amount is [Ti] and the N amount is [N], it is preferable to satisfy [N] - (14/48)[Ti] ≤ 0.

B: 0.0005 to 0.0020%

[0023] B improves the resistance to cold-work embrittlement when B exists in a solid solution state. To achieve such an effect, the B amount needs to be 0.0005% or more. However, a B amount of more than 0.0020% facilitates weld cracking. Thus, the B amount is in the range of 0.0005 to 0.0020%.

Cu: 0.05 to 0.5%

[0024] Cu is an element that is effective for imparting higher strength without deteriorating formability and for preventing the formation of humping bead during high speed plasma welding. In particular, the effects are increased when Cu coexists with O controlled within the range described below in the steel. To achieve such effects, the Cu amount needs to be 0.05% or more.

[0025] However, a Cu amount of more than 0.5% saturates the effects and significantly deteriorates surface quality. Thus, the Cu amount is in the range of 0.05 to 0.5%. The reason why the formation of humping bead during high speed plasma welding can be prevented when Cu coexists with 0 is uncertain, but it is believed that the viscosity of the steel melted during welding is optimized, which improves the flowability of molten steel.

Ni: 0.03 to 0.5%

[0026] The content of Cu described above easily deteriorates surface quality. To prevent it, a Ni amount of 0.03% or more needs to be added. However, a Ni amount of more than 0.5% saturates the effect. Thus, the Ni amount is in the range of 0.03 to 0.5%. Assuming that the Ni amount is [Ni] and the Cu amount is [Cu], it is preferable to satisfy 0.25 x [Cu] ≤ [Ni] ≤ 0.75 x [Cu] .

[0027] Although the balance is Fe and incidental impurities, 0: 0.0025 to 0.0080% or at least one of Se: 0.0005 to 0.01% and Te: 0.0005 to 0.01% is preferably further contained because of the following reasons.

O: 0.0025 to 0.0080%

[0028] As described above, the formation of humping bead during high speed plasma welding can be further suppressed when 0 coexists with Cu. It is believed that the viscosity and surface tension of the molten steel during welding is further optimized when O coexists with Cu. To achieve such an effect, the 0 amount in the steel needs to be 0.0025% or more, preferably 0.0040% or more. However, an 0 amount of more than 0.0080% saturates the effect, increases the cost for treating a slab surface due to a large number of blowholes of a continuous casting slab, and deteriorates the formability of the steel because of an increase in the number of inclusions.

Se: 0.0005 to 0.01% and Te: 0.0005 to 0.01%

[0029] As with 0, Se and Te optimize the viscosity and surface tension of the molten steel during welding and prevent the formation of humping bead during high speed plasma welding when they coexist with Cu. To achieve such effects, the Se or Te amount needs to be 0.0005% or more. However, a Se or Te amount of more than 0.01% saturates the effects.

2) Microstructure

[0030] In terms of formability, a microstructure constituted by a ferrite single phase is required. The ferrite single phase herein may be either a polygonal ferrite phase or a bainitic ferrite phase or a mixture thereof. To ensure a TS of 440 MPa and prevent the excessive softening of a welded portion, the average grain diameter of the ferrite phase is preferably 50 μm or less.

3) Manufacturing Conditions

[0031] The high strength cold rolled steel sheet of the present invention can be manufactured by a method including the steps of hot-rolling a slab having the composition described above, coiling at a coiling temperature of 680˚C or less, pickling, cold-rolling at a reduction ratio of 40% or more, and performing recrystallization annealing at 700 to 850˚C.

[0032] Coiling Temperature after Hot Rolling: 680˚C or less When the coiling temperature is more than 680˚C, a chemical compound of P and Fe, Ti, or the like is easily formed, which impedes the development of a {111} texture that is preferred for deep-drawing formability when cold-rolling and annealing performed later. Thus, the coiling temperature is 680˚C or less, preferably 650˚C or less.

Reduction Ratio of Cold Rolling: 40% or more

[0033] In terms of formability, the reduction ratio is 40% or more. In terms of improvement in formability and, particularly, deep drawability, the reduction ratio is preferably 50% or more.

Recrystallization Annealing Temperature: 700 to 850˚C

[0034] The annealing temperature needs to be 700˚C or more for recrystallization. However, when the annealing temperature exceeds 850˚C, ferrite grains are coarsened, which decreases strength or deteriorates surface quality. Thus, the recrystallization annealing temperature is in the range of 700 to 850˚C. To sufficiently perform recrystallization, a steel sheet is preferably held at 750˚C or more for 30 seconds or longer.

[0035] Manufacturing conditions of typical methods can be applied to other manufacturing conditions of the present invention. In other words, steel is smelted in a converter or an electric furnace to form a slab through continuous casting. For hot rolling, the slab may be rolled after heat treatment, directly rolled without heat treatment, or rolled after short-time heat treatment. Hot rolling may be performed at a finishing temperature equal to or higher than the Ar_3 transformation temperature as with typical procedures. The recrystallization annealing can be performed by box annealing or continuous annealing. After the annealing, skin pass rolling may be performed, for example, for the purpose of the adjustment of surface roughness and the planarization of a plate shape. Subsequently, surface treatments such as a chemical conversion treatment and a plating treatment may be conducted.

Example 1

[0036] Each of steel Nos. 1 to 7 having an elemental composition of 0:002% C-0.2% Si-1.8% Mn-0.05% P-0.005% S-0.02% sol. Al-0.003% N-0.04% Ti-0.0010% B with Cu, 0, and Se shown in Table 1 was smelted by vacuum melting, heated at 1200˚C for 1 hour, and then rough-rolled to make a sheet bar having a thickness of 35 mm. The sheet bar was heated at 1250˚C for 1 hour and finish-rolled such that the finish rolling entering temperature was 900˚C after seven passes. Subsequently, heat treatment corresponding to coiling was performed at 580˚C for 1 hour to obtain a hot rolled steel sheet having a thickness of 4 mm. The hot rolled steel sheet was descaled through pickling and cold-rolled at a reduction ratio of 60% to obtain a cold rolled steel sheet having a thickness of 1.6 mm. Recrystallization annealing in which heating is conducted at 830˚C for 180 sec and cooling is then conducted at a cooling rate of 10˚C/sec was performed using a salt bath. After pickling was performed in order to remove the salt attached to the surface of the steel sheet, skin pass rolling was conducted at an elongation percentage of 0.5%.

[0037] Steel sheets having the same composition were plasma-welded at a welding speed of 0.2 to 1.4 m/min under the following fixed conditions to investigate the "presence" or "absence" of humping bead: welding current: 60A, Ar gas flow rate for plasma: 0.6 L/min, Ar gas flow rate for shield: 10 L/min, nozzle size: 2.0 mmϕ, and nozzle-sample distance: 3 mm.

Table 1 shows the results.

[0038] In the existing plasma welding, the maximum speed that can achieve welding without forming humping bead was about 0.2 to 0.4 m/min. In contrast, humping bead was not formed at a high welding speed of 1 m/min in the sample (steel No. 3) containing Cu according to the present invention and at a high welding speed of 1 m/min or more in the samples (steel Nos. 4 to 7) further containing 0 and Se. Accordingly, the samples of the present invention have high speed plasma weldability.

Table 1

Steel No.	Cu (% by mass)	Ni (% by mass)	O (% by mass)	Se (% by mass)	Welding speed (m/min) and Humping bead presence (x) absence (0)						
					0.2	0.4	0.6	0.8	1.0	1.2	1.4
1	0	0	<0.002	0	○	×					
2	0.01	0.05	<0.002	0	○	○	×				
3	0.05	0.03	<0.002	0	○	○	○	○	○	×	
4	0.05	0.03	0.0040	0	○	○	○	○	○	○	
5	0.1	0.05	0.0030	0	○	○	○	○	○	○	
6	0.1	0.05	0.0050	0	○	○	○	○	○	○	○
7	0.1	0.05	0.0030	0.0010	○	○	○	○	○	○	○

Example 2

[0039] Each of steel Nos. A to F having compositions shown in Table 2 was smelted to obtain a slab through continuous casting. The slab was heated at 1200˚C and then finish-rolled at a finishing temperature of 900˚C. The slab was coiled at a coiling temperature of 580˚C to obtain hot rolled steel sheets having thicknesses of 6 mm and 4 mm. The hot rolled steel sheets were pickled and cold-rolled at a reduction ratio of 60% to obtain cold rolled steel sheets having thicknesses of 2.4 mm and 1.6 mm. Continuous annealing was performed at an annealing temperature of 830˚C and skin pass rolling was conducted at an elongation percentage of 0.5%.

[0040] Steel sheets having the same composition were plasma-welded in accordance with the combinations of sheet thickness shown in Table 3 under the following fixed conditions to investigate the "presence" or "absence" of humping bead: welding current: 60A, Ar gas flow rate for plasma: 0.6 L/min, Ar gas flow rate for shield: 10 L/min, nozzle size: 2.0 mmϕ, nozzle-sample distance: 3 mm, and welding speed: 1 m/min. Furthermore, TS and total elongation El in a direction perpendicular to the rolled direction of the obtained steel sheets and an average r value were measured using JIS 5 test pieces.

[0041] Table 3 shows the results. The steel sheets having compositions of invention examples exhibit a TS of 440 MPa or more and are excellent in formability. For the steel sheets, humping bead is not formed during high speed plasma welding.

Table 2

Steel No.	Composition (% by mass)														Note
	C	Si	Mn	P	S	sol.Al	N	Ti	B	Cu	Ni	O	(Mn/55)/(S/32)	Other	
A	0.0015	0.2	1.9	0.079	0.007	0.050	0.0016	0.037	0.001	0.09	0.05	<0.002	158	-	within the scope of the invention
B	0.0025	0.2	2.0	0.075	0.007	0.050	0.0015	0.035	0.0015	0.12	0.05	0.005	166	-	within the scope of the invention
C	0.0015	0.7	1.2	0.030	0.006	0.030	0.0020	0.061	0.0015	0.06	0.035	0.003	116	Se:0.005	within the scope of the invention
D	0.0012	0.6	1.3	0.036	0.008	0.026	0.0007	0.032	0.0006	0	0.06	<0.002	95	-	outside the scope of the invention
E	0.0015	0.5	0.8	0.030	0.007	0.030	0.0020	0.06	0.0015	0.15	0.080	0.005	66	-	outside the scope of the invention
F	0.0015	0.1	0.3	0.075	0.003	0.050	0.0015	0.035	0.0015	0.1	0.05	0.007	58	-	outside the scope of the invention

Table 3

Steel	Combination No. of sheet thickness	TS (MPa)	El (%)	Average r value	Humping bead presence (Note (×) absence (○)	Note
A	1.6/1.6	450	40	1.6	○	Invention Example
B	1.6/1.6	510	35	1.4	○	Invention Example
B	2.4/1.6	510	35	1.4	○	Invention Example
C	2.4/1.6	470	38	1.5	○	Invention Example
D	1.6/1.6	480	38	1.5	×	Comparative Example
E	1.6/1.6	420	43	1.4	○	Comparative Example
F	1.6/1.6	285	60	1.8	○	Comparative Example
TS, El, and r value are material property values in 1.6 mmt						

Claims

1. A high strength cold rolled steel sheet that is excellent in weldability and has a tensile strength of 440 MPa or more, comprising a composition including C: 0.0005 to 0.005%, Si: 0.1 to 1.0%, Mn: 1 to 2.5%, P: 0.01 to 0.2%, S: 0.015% or less, sol. Al: 0.05% or less, N: 0.007% or less, Ti: 0.01 to 0.1%, B: 0.0005 to 0.0020%, Cu: 0.05 to 0.5%, and Ni: 0.03 to 0.5% by mass with the balance Fe and incidental impurities; and a microstructure constituted by a ferrite single phase.

2. The high strength cold rolled steel sheet according to Claim 1 that is excellent in weldability and has a tensile strength of 440 MPa or more, wherein the composition further includes O: 0.0025 to 0.0080% by mass.

3. The high strength cold rolled steel sheet according to Claim 1 or 2 that is excellent in weldability and has a tensile strength of 440 MPa or more, wherein the composition further includes at least one of Se: 0.0005 to 0.01% and Te: 0.0005 to 0.01% by mass.

4. A method for manufacturing a high strength cold rolled steel sheet that is excellent in weldability and has a tensile strength of 440 MPa or more, comprising the steps of hot-rolling a slab having the composition described in any one of Claims 1 to 3, coiling at a coiling temperature of 680˚C or less, pickling, cold-rolling at a reduction ratio of 40% or more, and performing recrystallization annealing at 700 to 850˚C.

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, B21B3/00(2006.01)i, C21D9/46(2006.01)i, C22C38/16 (2006.01)i, C22C38/60(2006.01)i

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, B21B3/00, C21D9/46, C22C38/16, C22C38/60

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2009
Kokai Jitsuyo Shinan Koho	1971-2009	Toroku Jitsuyo Shinan Koho	1994-2009

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 7-188772 A (Kobe Steel, Ltd.), 25 July, 1995 (25.07.95), Claims 1 to 3; Par. Nos. [0022] to [0024], [0027], [0028] (Family: none)	1,4
X	JP 6-212276 A (Kawasaki Steel Corp.), 02 August, 1994 (02.08.94), Claim 1; Par. Nos. [0024] to [0026] (Family: none)	1,2,4
X	JP 6-100980 A (Kawasaki Steel Corp.), 12 April, 1994 (12.04.94), Claims 1, 3; Par. Nos. [0029] to [0031], [0034], [0036] (Family: none)	1

☒ 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	Date of mailing of the international search report
30 September, 2009 (30.09.09)	13 October, 2009 (13.10.09)

Name and mailing address of the ISA/	Authorized officer
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Form PCT/ISA/210 (second sheet) (April 2007)

INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 8-291364 A (NKK Corp.), 05 November, 1996 (05.11.96), Claim 3; Par. Nos. [0046] to [0048] (Family: none)	1-4

Form PCT/ISA/210 (continuation of second sheet) (April 2007)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- JP 1149943 A **[0005]**
- JP 2232342 A **[0005]**
- JP 2003094170 A **[0005]**