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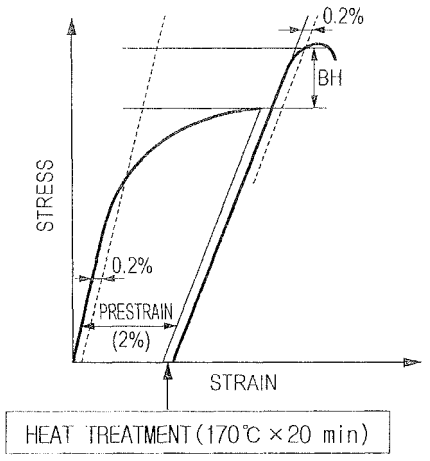
# (54) HIGH-STRENGTH ELECTRICAL-RESISTANCE-WELDED STEEL PIPE AND MANUFACTURING METHOD THEREFOR

(57) A high-strength electric resistance welded steel tube suitable for use in shock absorbing members of automotives is provided.

The high-strength electric resistance welded steel tube has a composition including, in terms of percent by mass, C: 0.05 to 0.20%, Si: 0.5 to 2.0%, Mn: 1.0 to 3.0%, P: 0.1% or less, S: 0.01% or less, Al: 0.01 to 0.1%, N: 0.005% or less, and the balance being Fe and unavoidable impurities; and a structure which is a dual phase structure including a ferrite phase and a martensite phase, with a volume ratio of the martensite phase being 20 to 60%, wherein a tensile strength TS is 1180 MPa or more, an elongation El in a tube axis direction is 10% or more, and a yield ratio is less than 90%; and after application of a 2% prestrain and baking finishing that includes a heat treatment of 170°C × 10 min, a strength increase (BH value) is 100 MPa or more and a yield ratio is 90% or more.

FIG. 2

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## Description

Technical Field

**[0001]** The present invention relates to high-strength electric resistance welded steel tubes suitable for use in crash members for automobiles such as door impact beams, cross members, and pillars, and, in particular, to a high-strength electric resistance welded steel tube having both excellent formability and shock absorption.

Background Art

**[0002]** In recent years, for the purposes of achieving enhanced safety of automobiles and in particular ensuring safety of occupants, shock absorbing members for absorbing impact energy upon collision are installed in automotive bodies. For example, a high-strength steel tube having a desired high strength and a martensitic structure induced by a quenching treatment has been applied to door impact beams, i.e., shock absorbing members, as described in Patent Literature 1.

**[0003]** Patent Literature 1 discloses a method for producing an electric resistance welded steel tube for machine structural use, the method including quenching a steel tube containing C: 0.15 to 0.22%, Mn: 1.5% or less, Si: 0.5% or less, Ti: 0.04% or less, B: 0.0003 to 0.0035%, N: 0.0080% or less and one or more selected from Ni: 0.5% or less, Cr: 0.5% or less, and Mo: 0.5% or less, wherein the electric resistance welded steel tube for machine structural use has a tensile strength of 120 kgf/mm$^2$ or more. According to the technology described in Patent Literature 1, a high-strength steel tube that has a tensile strength of 120 kgf/mm$^2$ or more and an excellent elongation of 10% or more, that can be used for reinforcing automobiles, and that can be applied to door impact bars (door impact beams) and center cores for bumpers can be obtained by performing a heat treatment once.
Steel sheets having a tensile strength of 120 kgf/mm$^2$ or more are also disclosed in Patent Documents 2 to 7 which disclose the technologies related to high-strength cold-rolled steel sheets that are used in automotive structural members and have a tensile strength of 900 MPa or more. These steel sheets all have a dual phase structure containing a ferrite phase and a martensite phase or a structure containing a bainite phase and a retained austenite phase in addition to these phases, and the upper limits of the area fractions of the bainite phase and the retained austenite phase are defined. According to these literatures, it is because of this structure that the steel sheets exhibit both formability and high strength.

Citation List

Patent Literature

**[0004]**

PTL 1: Japanese Unexamined Patent Application Publication No. 3-122219
PTL 2: Japanese Unexamined Patent Application Publication No. 2010-255094
PTL 3: Japanese Unexamined Patent Application Publication No. 2010-126787
PTL 4: Japanese Unexamined Patent Application Publication No. 2009-242816
PTL 5: Japanese Unexamined Patent Application Publication No. 2009-203550
PTL 6: Japanese Unexamined Patent Application Publication No. 2007-100114
PTL 7: Japanese Unexamined Patent Application Publication No. 2005-163055

Summary of Invention

Technical Problem

**[0005]** The technology described in Patent Literature 1 does not present a serious problem in the cases where steel tubes are used straight without being subjected to any working, such as in the cases of door impact beams. However, steel tubes that are used in other automotive shock absorbing members such as cross members and pillars that require complicated forming to make various shapes are required to exhibit excellent formability in addition to the high strength. The technologies described in Patent Literatures 2 to 5 have problems in that, because of the low cooling rate after holding of heat during annealing, precipitation of carbides occurs, the solute C content in the ferrite becomes insufficient, the strength increase (bake hardening value or BH value) caused by a prestrain-baking finishing treatment is small, and a BH value of 100 MPa or more is not reliably achieved.
The technology described in Patent Literature 6 does not consider the cooling rate from the holding of heat during annealing to the start of water quenching. For example, when the time taken up to the start of water quenching is long due to the layout of the production line and thus the cooling rate is low, the C content distribution proceeds between

ferrite and austenite and thus the amount of the solute C remaining in the ferrite presumably contributing to the bake hardenability is insufficient. Thus, Patent Literature 6 does not describe or anticipate that the BH value of 100 MPa or more is ensured.

In the technology described in Patent Literature 7, the cooling rate during finish annealing is low, e.g., 550 °C/min at maximum in Examples, and the elongation is only about 8%. The elongation is generally low and 11% at maximum. Accordingly, when a steel sheet produced by the technology described in Patent Literature 7 is formed into an electric resistance welded steel tube, the elongation will further decrease due to the processing strain applied during tube forming and the resulting steel tube does not reliably achieve an elongation of 10% or more.

Under these requirements, it is an object of the present invention to provide a high-strength electric resistance welded steel tube that has excellent formability and that can ensure excellent shock absorption suitable for use in automotive shock absorbing members and a method for producing the high-strength electric resistance welded steel tube.

**[0006]** Note that "high strength" refers to a tensile strength TS of 1180 MPa or more.

Moreover, "excellent formability" refers to an elongation El of 10% or more and preferably 12% or more in the tube axis direction and a yield ratio (= 0.2% proof stress/tensile strength x 100 (%)) of less than 90% determined by a tensile test using a JIS No. 12 tensile test specimen (GL: 50 mm) defined by Japanese Industrial Standards (JIS). Furthermore, "excellent shock absorption" refers to the case in which the strength increase (bake hardening value or BH value), i.e., the difference between the 0.2% proof stress after heat-treating (baking finishing) a 2% restrained tube at 170°C for 10 minutes and the strength upon application of a 2% prestrain, is 100 MPa or more and the yield ratio in the tube axis direction is 90% or more. The BH value is defined in Fig. 2. Solution to Problem

**[0007]** In order to achieved the object described above, the inventors of the present application have conducted extensive studies to find ways to improve the formability of electric resistance welded steel tubes while maintaining the high strength. As a result, the inventors have found that an electric resistance welded tube having excellent formability can be produced by using, as a material for a steel tube, a steel sheet (cold-rolled steel sheet) having a ferrite-martensite dual phase structure, excellent formability, and a desired bake hardenability and employing a tube production method with which a tube can be formed without significantly degrading the excellent formability of the material for a steel tube. After this electric resistance welded tube is worked to have a desired component shape, a heat treatment (baking finishing) is performed to increase the strength so that the proof stress is improved and the resulting component can reliably achieve excellent shock absorption.

**[0008]** The present invention has been made based on the above-described findings and conducting further studies. The summary of the present invention is as follows:

(1) A high-strength electric resistance welded steel tube having a composition including, in terms of percent by mass, C: 0.05 to 0.20%, Si: 0.5 to 2.0%, Mn: 1.0 to 3.0%, P: 0.1% or less, S: 0.01% or less, Al: 0.01 to 0.1%, N: 0.005% or less, and the balance being Fe and unavoidable impurities, and a structure which is a dual phase structure including a ferrite phase and a martensite phase, with a volume ratio of the martensite phase being 20 to 60%, in which a tensile strength TS is 1180 MPa or more, an elongation El in a tube axis direction is 10% or more, and a yield ratio is less than 90%; and after application of a 2% prestrain and baking finishing that includes a heat treatment of 170°C x 10 min, a strength increase (BH value) is 100 MPa or more and a yield ratio is 90% or more.

**[0009]**

(2) In the high-strength electric resistance welded steel tube of (1), the composition further includes, in terms of percent by mass, at least one selected from Cu: 1.0% or less, Ni: 1.0% or less, Cr: 0.5% or less, Mo: 0.5% or less, Nb: 0.05% or less, Ti: 0.05% or less, W: 0.05% or less, and B: 0.0050% or less.

(3) In the high-strength electric resistance welded steel tube of (1) or (2), the composition further includes, in terms of percent by mass, Ca: 0.0050% or less and/or REM: 0.0050% or less.

**[0010]** (4) A method for producing a high-strength electric resistance welded steel tube, the method including a hot rolling process of hot-rolling a steel into a hot-rolled sheet; a cold-rolling process of pickling the hot-rolled sheet and cold-rolling the pickled hot-rolled sheet to prepare a cold-rolled sheet; an annealing process of annealing the cold-rolled sheet into a cold-rolled annealed sheet so as to prepare a material for a steel tube; and a tube production process of continuously forming the material for a steel tube into a substantially cylindrical open tube and electric-resistance-welding the open tube to prepare an electric resistance welded tube. The steel has a composition including, in terms of percent by mass, C: 0.05 to 0.20%, Si: 0.5 to 2.0%, Mn: 1.0 to 3.0%, P: 0.1% or less, S: 0.01% or less, Al: 0.01 to 0.1%, N: 0.005% or less, and the balance being Fe and unavoidable impurities. In the hot-rolling process, the hot rolling is conducted at a finishing temperature equal to or higher than an $Ar_3$ transformation point and at a coiling temperature of 500 to 700°C to prepare the hot-rolled sheet. In the annealing process, after the cold-rolled sheet is heated to and soaked at a temperature in a two-phase temperature region ranging from an $Ac_1$ transformation point to an $Ac_3$ transformation

point, the sheet is cooled at an average cooling rate (defined as "average cooling rate 1") of 10°C/s or more to a temperature in the range or 600 to 750°C and then rapidly cooled at an average cooling rate (defined as "average cooling rate 2") of 500°C/s or more from the temperature in the range of 600 to 750°C to room temperature, and then a tempering treatment that includes re-heating the sheet to a temperature in the range of 150 to 300°C is performed so as to prepare a cold-rolled annealed sheet. The forming is performed by a roll forming method involving a cage roll method. The electric resistance welded tube has a tensile strength TS of 1180 MPa or more, an elongation El in a tube axis direction of 10% or more, and a yield ratio less than 90%, and exhibits, after application of a 2% prestrain and baking finishing that includes a heat treatment of 170°C x 10 min, a strength increase (BH value) of 100 MPa or more and a yield ratio of 90% or more.

**[0011]**

(5) In the method for producing a high-strength electric resistance welded steel tube of (4), the composition further includes, in terms of percent by mass, at least one selected from Cu: 1.0% or less, Ni: 1.0% or less, Cr: 0.5% or less, Mo: 0.5% or less, Nb: 0.05% or less, Ti: 0.05% or less, W: 0.05% or less, and B: 0.0050% or less.

(6) In the method for producing a high-strength electric resistance welded steel tube in (4) or (5), the composition further includes, in terms of percent by mass, Ca: 0.0050% or less and/or REM: 0.0050% or less.

Advantageous Effects of Invention

**[0012]** According to the present invention, a high-strength electric resistance welded steel tube that has excellent formability suitable for use in shock absorbing members of automotive and that can reliably achieve excellent shock absorption after being formed into an actual component shape can be produced at low cost and thus the present invention provides remarkable industrial advantages. Moreover, the high-strength electric resistance welded steel tube according to the present invention can be used not only in door impact beams but also in all types of automotive parts such as automotive shock absorbing components, e.g., cross members and pillars, that require formability, and automotive body parts.

Brief Description of Drawings

**[0013]**

[Fig. 1] Fig. 1 is a schematic diagram showing one example of a facility for producing an electric resistance welded tube, the facility employing a CBR roll forming method suitable for implementing the present invention.

[Fig. 2] Fig. 2 is a schematic diagram showing the definition of a strength increase (BH value) after baking finishing.

Description of Embodiments

**[0014]** The reasons for limitations on the composition of a high-strength electric resistance welded steel tube according to the present invention are first described. Hereinafter, mass% is simply denoted as % unless otherwise noted.

C: 0.05 to 0.20%

**[0015]** Carbon (C) strengthens the steel and the C content in the present invention needs to be 0.05% or more to ensure a desired strength. When the C content exceeds 0.20%, the weldability is degraded. Thus, in the present invention, the C content is limited to be in the range of 0.05 to 0.20% and more preferably in the range of 0.08 to 0.18%.

Si: 0.5 to 2.0%

**[0016]** Silicon (Si) serves as a deoxidizing agent, strengthens the steel by forming a solid solution, accelerates formation of ferrite, and is thus an important element for ensuring excellent formability. Silicon also causes solid solution strengthening of the ferrite phase to thereby suppress the martensite) phase fraction and achieve a desired high strength. The Si content needs to be 0.5% or more in order to attain these effects. In contrast, when the Si content exceeds 2.0%, large amounts of silicon oxides occur in the steel sheet surface and the chemical conversion treatability is thereby degraded. Accordingly, in the present invention, the Si content is limited to be in the range of 0.5 to 2.0% and preferably in the range of 1.0 to 1.8%.

Mn: 1.0 to 3.0%

**[0017]** Manganese (Mn) improves hardenability, promotes formation of the martensite phase, and increases the

strength of the steel. The Mn content of 1.0% is required in the present invention in order to reliably achieve a desired strength. In contrast, when the Mn content exceeds 3.0%, segregation is accelerated, slab cracks tend to occur during casting, and the amount of the martensite phase increases excessively, thereby degrading the formability. Accordingly, the Mn content is limited to be in the range of 1.0 to 3.0% and preferably in the range of 1.5 to 2.5%.

P: 0.1% or less

**[0018]** Phosphorus (P) is an impurity in the present invention and the P content is preferably as low as possible to avoid adverse effects on formability. However, excessively decreasing the P content increases the refining cost. Accordingly, the P content is limited to 0.1% or less which does not substantially cause adverse effects. Preferably, the P content is 0.05% or less.

S: 0.01% or less

**[0019]** As with phosphorus (P), sulfur (S) is an impurity in the present invention and the S content is preferably as low as possible to avoid adverse effects on formability. However, excessively decreasing the S content increases the refining cost. Accordingly, the upper limit of the S content is set to 0.01% and preferably 0.005% or less.

Al: 0.01 to 0.1%

**[0020]** Aluminum (Al) serves as a deoxidizing agent and the Al content needs to be 0.01% or more in order to achieve this effect. When the Al content exceeds 0.1%, saturation occurs and the effect that corresponds to the content cannot be anticipated. Accordingly, the Al content is limited to be in the range of 0.01 to 0.1% and preferably in the range of 0.01 to 0.08%.

N: 0.005% or less

**[0021]** Nitrogen (N) strengthens the steel but decreases the formability and the content of nitrogen as an impurity is preferably decreased as much as possible. However, excessively decreasing the N content increases the refining cost. Accordingly, the N content is limited to 0.005% or less which does not have substantial adverse effect. Preferably, the N content is 0.004% or less.

While the components described heretofore are the basic components, at least one selected from Cu: 1.0% or less, Ni: 1.0% or less, Cr: 0.5% or less, Mo: 0.5% or less, Nb: 0.05% or less, Ti: 0.05% or less, W: 0.05% or less, and B: 0.0050% or less and/or at least one selected from Ca: 0.0050% or less and REM: 0.0050% or less may be contained in addition to the basic composition.

**[0022]** Copper (Cu), nickel (Ni), chromium (Cr), molybdenum (Mo), niobium (Nb), titanium (Ti), tungsten (W), and boron (B) all increase the strength of the steel and one or more of these elements can be selected as needed and added.

Cu: 1.0% or less

**[0023]** Copper (Cu) increases the strength of the steel and improves the corrosion resistance, and may be contained as needed. These effects can be achieved at a Cu content of 0.05% or more but the hot workability is degraded at a Cu content exceeding 1.0%. Accordingly, when copper is to be used, the Cu content is preferably limited to 1.0% or less and more preferably 0.08 to 0.5%.

Ni: 1.0% or less

**[0024]** Nicker (Ni) increases the strength of the steel and improves the corrosion resistance and may be contained as needed. These effects can be achieved at a Ni content of 0.05% or more. However, since nickel is an expensive element, incorporation of a large quantity of Ni exceeding 1.0% increases the cost of the raw material. Accordingly, when the nickel is to be used, the Ni content is preferably limited to 1.0% or less and more preferably 0.08 to 0.5%.

Cr: 0.5% or less

**[0025]** Chromium (Cr) improves the hardenability and thus increases the strength of the steel, and improves the corrosion resistance. Chromium may be contained as needed. These effects are achieved at a Cr content of 0.05% or more. However, the formability decreases at a Cr content exceeding 0.5%. Accordingly, when chromium is to be used, the Cr content is preferably limited to 0.5% or less and more preferably 0.05 to 0.4%

Mo: 0.5% or less

**[0026]** Molybdenum (Mo) improves the hardenability and increases the strength of the steel through precipitation strengthening, and may be contained as needed. These effects are achieved at a Mo content of 0.05% or more. However, the ductility decreases and the cost of raw material increases at a Mo content exceeding 0.5%. Accordingly, when molybdenum is to be used, the Mo content is preferably limited to 0.5% or less and more preferably 0.1 to 0.4%.

Nb: 0.05% or less

**[0027]** Niobium (Nb) reduces the size of crystal grains and increases the strength of the steel through precipitation strengthening, and may be contained as needed. Such effects are achieved at a Nb content of 0.005% or more but the ductility decreases at a Nb content exceeding 0.05%. Accordingly, when niobium is to be used, the Nb content is preferably limited to 0.05% or less and more preferably 0.008 to 0.03%.

Ti: 0.05% or less

**[0028]** Titanium (Ti) reduces the size of crystal grains and increases the strength of the steel through precipitation strengthening, and may be contained as needed. Such effects are achieved at a Ti content of 0.005% or more but the ductility decreases at a Ti content exceeding 0.05%. Accordingly, when titanium is to be used, the Ti content is preferably limited to 0.05% or less and more preferably 0.008 to 0.03%.

W: 0.05% or less

**[0029]** Tungsten (W) increases the strength of the steel through precipitation strengthening and may be contained as needed. Such an effect is achieved at a W content of 0.01% or more but the ductility decreases at a W content exceeding 0.05%. Accordingly, when tungsten is to be used, the W content is preferably limited to 0.05% or less and more preferably 0.01 to 0.03%.

B: 0.0050% or less

**[0030]** Boron (B) improves the hardenability, thereby helping adjust the martensite fraction to be within a particular range and increases the strength of the steel, and may be contained as needed. Such effects are achieved at a B content of 0.0005% or more. However, saturation occurs and effects corresponding to the content cannot be anticipated at a B content exceeding 0.0050%, which is economically disadvantageous. Accordingly, when boron is to be used, the B content is preferably limited to 0.0050% or less and more preferably 0.001 to 0.003%.

Ca: 0.0050% or less and/or REM: 0.0050% or less

**[0031]** Calcium (Ca) and a rare earth element (REM) improve the ductility through morphological control of sulfide-based inclusions and may be contained as needed. Such an effect is achieved at a Ca content and a REM content of 0.0020% or more. However, at a Ca content and a REM content exceeding 0.0050%, the amount of inclusions becomes excessively large and the cleanness of the steel is decreased. Accordingly, when calcium and the rare earth element are to be used, the Ca content and the REM content are both preferably limited to 0.0050% or less and more preferably 0.0020 to 0.0040%.

The balance other than the components described above is Fe and unavoidable impurities.

**[0032]** Next, the reasons for limitations on the structure of the steel tube of the present invention are described.

A steel tube of the present invention has a dual phase structure including 20 to 60% of a martensite phase in terms of volume ratio with the remainder being a ferrite phase. Because of this structure, a desired high strength, excellent formability, and excellent bake hardenability are all attained.

**[0033]** A desired high strength is not achieved at a martensite phase fraction less than 20 vol% because the ferrite phase is dominant in the structure. At a martensite phase fraction exceeding 60 vol%, the martensite phase becomes dominant and a desired formability may not be ensured. Accordingly, the martensite phase fraction in the structure is limited to be in the range of 20 to 60% in terms of a volume ratio and preferably 40 to 55% in terms of volume ratio.

**[0034]** Next, a preferable method for producing the steel tube of the present invention is described.

In the present invention, a steel is subjected to a hot-rolling process, a cold-rolling process, and an annealing process to form a material for a steel tube, and the material for a steel tube is subjected to a tube production process to form an electric resistance welded tube.

The method for producing the steel is not particularly limited. Preferably, a molten steel having the above-described

composition is refined by a common refining method using a converter or the like and formed into a slab or the like by a continuous casting method or an ingoting-rolling method so as to form a steel.

**[0035]** The steel is subjected to a hot-rolling process through which the steel is hot-rolled into a hot-rolled sheet. The steel may be reheated after cooling or, when the steel holds a particular quantity of heat, may be directly sent to be hot-rolled without reheating. When reheating is to be performed, the heating temperature is preferably 1000 to 1250°C. When the heating temperature during reheating is less than 1000°C, deformation resistance is high and the load imposed on a rolling machine is excessively large, thereby possibly making rolling difficult. In contrast, when the heating temperature exceeds 1250°C, the crystal grains become coarse and the ductility decreases significantly.

**[0036]** Hot rolling includes rough rolling and finish rolling. The conditions of the rough rolling are any as long as a sheet bar having particular dimension and shape is obtained. The finish rolling involves rolling at a finishing temperature equal to or higher than the $Ar_3$ transformation point of a steel strip, i.e., the material to be rolled. After the finish rolling, the steel strip is coiled at a coiling temperature of 500 to 700°C.

When the finishing temperature is lower than the $Ar_3$ transformation point, finishing rolling involves rolling at an ($\alpha + \gamma$) two-phase region and the structure is a mixed grain structure in which significantly coarse crystal grains and fine crystal grains are mixed. Thus, when a cold-rolling process and an annealing process are performed thereafter, satisfactory formability may not be reliably obtained and rough surfaces occur as a result of working such as press forming and bending work. Accordingly, the finishing temperature of the hot-rolling is limited to a temperature equal to or higher than the $Ar_3$ transformation point. At a coiling temperature less than 500°C, a hard phase is generated during cooling, the roll load increases during cold-rolling, and thus the productivity is decreased. When the coiling temperature is high exceeding 700°C, a non-transformed austenite transforms into pearlite and thus formability is decreased. Thus, the coiling temperature is limited to be in the range of 500 to 700°C. The coiling temperature is preferably 650°C or less.

**[0037]** The hot rolled sheet obtained through the hot-rolling process is next subjected to a cold-rolling process of pickling the hot-rolled sheet and then cold-rolling the pickled sheet into a cold-rolled sheet. The conditions of the cold-rolling process such as reduction during cold rolling are not particularly defined.

The resulting cold-rolled sheet is subjected to an annealing process to form a cold-rolled annealed sheet.

The annealing process is crucial in the present invention in order to reliably achieve the desired formability and the desired bake hardenability (BH). The annealing process is preferably conducted in a continuous annealing line.

**[0038]** In the annealing process, after the cold-rolled sheet is heated to a temperature in a two-phase temperature range ranging from the $Ac_1$ transformation point to the $Ac_3$ transformation point and soaked thereat, the sheet is cooled (average cooling rate 1) at an average cooling rate of 10 °C/sec or more to a temperature in the range of 600 to 750°C and then rapidly cooled (average cooling rate 2) from the temperature in the range of 600 to 750°C to room temperature at an average cooling rate of 500 °C/s or more. The sheet is then subjected to a tempering treatment of reheating the sheet to a temperature in the range of 150 to 300°C and thereby made into a cold-rolled annealed sheet. Note that in order to stably achieve the desired high strength and the bake hardenability, the cooling rate (average cooling rate 1) from the soaking temperature to the temperature at the start of rapid cooling is preferably 15 °C/s or more and the average cooling rate (average cooling rate 2) in the rapid-cooling treatment is preferably 800 °C/s or more, more preferably 1000 °C/s or more, and most preferably 1100 °C/s or more.

**[0039]** When the heating and soaking temperature is outside the two-phase temperature region ranging from the $Ac_1$ transformation point to the $Ac_3$ transformation point, a (ferrite + martensite) structure having a desired structural fraction cannot be reliably obtained in the subsequent rapid cooling. When the cooling rate (average cooling rate 1) from the heat holding temperature to the temperature at the start of rapid cooling is less than 10 °C/s, distribution of the C content proceeds between ferrite and austenite, the amount of solute C in the ferrite presumably contributing to bake hardenability becomes small, and thus the desired bake hardenability is not obtained. When the temperature at the start of rapid cooling is outside the range of 750°C to 600°C, a (ferrite + martensite) structure having a desired structural fraction cannot be obtained. When the temperature at the start of rapid cooling exceeds 750°C, the ductility decreases. When the temperature at the start of rapid cooling is less than 600°C, a desired high strength cannot be reliably obtained. The soaking time at the above-described temperature is preferably 30 s or longer.

**[0040]** When the cooling rate (average cooling rate 2) from the temperature in the range of 600 to 750°C to room temperature is less than 500 °C/s on average, the amount of transformed martensite is small, a (ferrite + martensite) structure having a desired structural fraction cannot be formed, a desired high strength cannot be reliably achieved, and a desired bake hardening value of 100 MPa or more is not obtained due to a small amount of solute C in the ferrite presumably contributing to the bake hardenability. The cooling rate in the rapid-cooling treatment is the average cooling rate from the temperature at the start of rapid cooling to 200°C.

The method of the rapid cooling treatment is not particularly limited but jet flow water is preferably used for cooling from the viewpoint of suppressing variation in the material in the steel sheet width direction and longitudinal direction.

In the annealing process of the present invention, a tempering treatment in which the sheet is reheated to a temperature in the range of 150 to 300°C is performed after the rapid cooling treatment so as to further improve the toughness. The toughness-improving effect is not anticipated at a tempering temperature less than 150°C.

**[0041]** The ductility decreases due to the low-temperature tempering brittleness at a reheating temperature exceeding 300°C. Accordingly, the temperature range for reheating is limited to 150 to 300°C.

The resulting cold-rolled annealed sheet may be subjected to skinpass rolling if needed. The rolling reduction of skinpass rolling is preferably 0.2% or more and 1.0% or less. At a rolling reduction of skinpass rolling less than 0.2%, a shape-correcting effect is not obtained. At exceeding 1.0%, deterioration of elongation becomes significant.

**[0042]** The cold-rolled annealed sheet (cold-rolled annealed steel strip) that have gone through the processes described above is used as a material for a steel tube, and a tube production process is conducted on the material for a steel tube to produce an electric resistance welded steel tube. The tube production process involves continuously forming the material for a steel tube into a substantially cylindrical open tube and electric-resistance-welding the open tube to form an electric resistance welded tube.

In the present invention, forming in the tube production process is performed by a roll forming method involving a cage roll method. The roll forming method involving the cage roll method refers to a forming technique with which small rolls called cage rolls are arranged along the tube outer surface so as to form a tube smoothly. Among the roll forming method involving the cage roll method, the roll forming method employing a chance-free bulge roll (CBR) method is preferred. According to this method, the strain applied to the strip during forming can be minimized and deterioration of the properties of the material caused by work hardening can be suppressed.

**[0043]** An example of a production facility for producing electric resistance welded tubes employing a CBR roll foaming method is shown in Fig. 1. According to the CBR roll forming method, two edges of a strip 1 is preliminarily formed with edge bend rolls 2, the central part of the strip is bend-worked by using center bend rolls 3 and cage rolls 4 so as to form an element tube having a vertically long oval figure, and four positions of the base tube in the tube circumferential direction are over-bent with fin pass rolls 5, followed by reducing so as to conduct stretch forming of the tube side portions and the bend and return forming of the over-bent portion to thereby make a round element tube (refer to Kawasaki Steel Giho Vol. 32 (2000), pp. 49 to 53). The CBR roll forming method is characterized in that the strain applied to the material (strip) is small and the variation in strain applied in the tube circumferential direction is small compared with a conventional breakdown (BD) method. While the round element tube obtained as such is being pressed with squeeze rolls 7, the butting edges are welded by welding means (high-frequency resistance welding) 6 so as to form an electric resistance welded tube 8.

**[0044]** A steel sheet (material for steel tubes) which is obtained by the production method described above and has high strength, excellent formability, and excellent bake hardenability is used to form a tube through the tube production process described above. Thus, the strain applied during the tube production can be minimized, the work hardening can be suppressed, and a high-strength electric resistance welded steel tube that has excellent formability and capable of ensuring excellent shock absorption after being processed into a component can be produced.

**[0045]** The resulting high-strength electric resistance welded steel tube has a tensile strength TS of 1180 MPa or more, an elongation El in the tube axial direction of 10% or more, and a yield ratio of less than 90%. After the steel tube is subjected to a 2% prestrain and a baking finishing treatment of heat-treating the prestrained steel tube at 170°C for 10 minutes, the strength increase (BH value) is 100 MPa or more and the yield ratio is 90% or more.

When the elongation of the electric resistance welded tube in the tube axial direction is less than 10%, the formability of the tube is degraded and it becomes difficult to form a desired shape. Preferably, the elongation is 12% or more. When the yield ratio of the electric resistance welded tube exceeds 90%, the formability of the tube is degraded and it becomes difficult to form a desired shape. The yield ratio is preferably 85% or less.

When the BH value of the electric resistance welded tube after baking finishing is less than 100 MPa, the energy absorbed upon collision becomes small and the tube does not satisfy the requirements for shock absorbing members. Preferably, the BH value is 110 MPa or more. The tube production process employed in producing the electric resistance welded tube of the present invention can minimize the strain applied during the tube production and the variation in strain applied in the tube circumferential direction is also decreased. Thus, in the electric resistance welded tube of the present invention, the variation in BH value among positions in the tube circumferential direction (i.e., the difference between the maximum value and the minimum value) is small and the BH values at the respective positions in the tube circumferential direction excluding the resistance welded portion are uniform and within the range of 100 to 130 MPa. When the yield ratio of the electric resistance welded tube is less than 90%, the electric resistance welded tube absorbs less energy upon collision and does not satisfy the requirements for shock absorbing members.

**[0046]** In the present invention, the heat treatment condition for baking finishing is set to 170°C × 10 min. However, this condition is the minimum heat treatment condition for obtaining the strength increase (BH value) of 100 MPa or more after the baking finishing. The electric resistance welded tube of the present invention will exhibit an strength increase (BH value) of 100 MPa or more after baking finishing under any other favorable conditions. As for the heat treatment conditions under which an strength increase (BH value) of 100 MPa or more is obtained after the baking finishing, a heating temperature in the range of 170 to 250°C is preferably held for 10 to 30 minutes. When the heating temperature is less than 170°C, the solute C required to yield the desired strength increase diffuses into dislocations and does not sufficiently pin the dislocations. As a result, the desired strength increase (BH value) is not reliably achieved

after the baking finishing. In contrast, when the temperature is excessively high exceeding 250°C, not only the productivity decreases, but also the tube may come to be heated in the blue brittleness range, possibly resulting in deterioration of the material.

**[0047]** When the holding time is as short as less than 10 minutes, the diffusion time is insufficient and the required amount of solute C cannot reach dislocations. Thus, the desired strength increase (BH value) cannot be reliably achieved after baking finishing. In contrast, when the holding time is longer than 30 minutes, the productivity is decreased. Preferably, the holding time is 25 minutes or shorter.

[EXAMPLES]

**[0048]** Molten steel samples indicated in Table 1 are refined in a converter and continuously casted into slabs (steels). These slabs (steels) are subjected to a hot-rolling process under conditions indicated in Table 2 to form hot-rolled sheets (thickness: 2.4 to 3.0 mm), followed by pickling. The hot-rolled sheets were subjected to a cold-rolling process of cold-rolling the sheets into cold-rolled sheets, and the cold-rolled sheets were subjected to an annealing process under conditions shown in Table 2 to form cold-rolled annealed sheets (thickness: 1.2 to 1.8 mm). As a result, materials for steel tubes were obtained. Test specimens were taken from the obtained materials for steel tubes and structural observation and a tensile test were carried out. The test methods were as follows.

Structural observation

**[0049]** Test specimens for structural observation were taken from the materials for steel tubes. Sections of the test specimens taken in the rolling direction were polished, corroded with nital, and observed with a scanning electron microscope (2000X magnification). Photographs of 10 or more areas of observation were taken, the types of the structures such as ferrite and martensite were identified with an image analyzer, and the structural fractions (volume ratios) of the respective phases were calculated.

(2) Tensile test

**[0050]** JIS No. 12 tensile test specimens (gauge length: 50 mm) were taken from the materials for steel tubes according to JIS Z 2201 so that the tensile direction matched the rolling direction. A tensile test was carried out according to JIS 2241 to determine the 0.2% proof stress YS (MPa), the tensile strength TS (MPa), and the elongation El (%). The yield ratio YR was calculated and the strength and formability were evaluated.
The results are shown in Table 3.

**[0051]** Each of the materials for steel tubes was formed by a CBR roll forming method into a substantially cylindrical open tube. While pressing the butting edges with squeeze rolls, the butting edges were electric resistance welded by high-frequency resistance welding. As a result, an electric resistance welded tube (48.6 mm in outer diameter and 1.2 to 1.8 mm in thickness) was obtained. Some of the steel tubes were formed by a BD forming method in the tube production process.

**[0052]** The resulting electric resistance welded tube was subjected to structural observation, tensile test, and baking finishing test to evaluate the structure, the tensile characteristics, and the bake hardenability. The test methods were as follows.

(1) Structural observation

**[0053]** Test specimens for structural observation were taken from each steel tube. Sections of the specimens taken in the tube axial direction were polished, corroded with nital, and observed with a scanning electron microscope (2000X magnification). Photographs of 10 or more areas of observation were taken, the types of the structures such as ferrite and martensite were identified with an image analyzer, and the structural fractions (volume ratios) of the respective phases were calculated as averages of 10 or more areas of observation.

(2) Tensile test

**[0054]** JIS No. 12 tensile test specimens (gauge length: : 50 mm) were taken from the steel tubes according to JIS Z 2201 so that the tensile direction matched the tube axis direction, and a tensile test was conducted according to JIS Z 2241 to calculate the 0.2% proof stress YS (MPa), the tensile strength TS (MPa), and the elongation El (%). The yield ratio YR was calculated and the strength and formability were evaluated.

(3) Baking finishing test

**[0055]** JIS No. 12 tensile test specimens were taken from the steel tubes according to JIS Z 2201 so that the tensile direction matched the tube axis direction. A 2% tensile strain was applied as a prestrain and a heat treatment at 170°C was conducted for 10 minutes to perform baking finishing. The tensile test specimens were taken at particular positions in the tube circumferential direction (eleven positions 30° spaced from each other in the circumferential direction while assuming the electric resistance welded portion to be 0°; the electric resistance welded portion was excluded).

**[0056]** A tensile test was conducted on the treated specimens. The 0.2% proof stress YS and the tensile strength TS after the baking finishing were determined and the yield ratio (=(YS/TS) x 100 (%)) after the baking finishing was calculated. The bake hardening value (BH value) was calculated as shown in Fig. 2 by determining the difference between the 0.2% proof stress after baking finishing and the strength after application of a 2% strain. The maximum value and the minimum value of the BH value were determined from among the positions in the circumferential direction. YS and TS are each an arithmetic mean of the values at the positions in the circumferential direction.

**[0057]** The results are shown in Table 4.

**[0058]** In all of examples of the present invention, an electric resistance welded tube that has a high strength, i.e., a tensile strength TS of 1180 MPa or more and excellent formability, i.e., an elongation El in the tube axial direction of 10% or more and a yield ratio (= (0.2% proof stress/tensile strength) x 100 (%)) in the tube axis direction of less than 90%, and exhibits excellent shock absorption, i.e., a BH value of 100 MPa or more and a yield ratio in the tube axis direction of 90% or more, after application of a prestrain of 2% or more and a heat treatment at 170°C $\times$ 10 min (baking finishing). In all of the examples of the present invention, the variation in BH value among the positions in the circumferential direction is small and the BIT values fall within the range of 100 to 130 MPa.

**[0059]** In contrast, comparative examples outside the range of the present invention have an insufficient strength, low formability, or an insufficient BH value.

The influence of the baking finishing conditions was also studied.

JIS No. 12 tensile test specimens were taken from the steel tube No. 1 (Example of the present invention) shown in Table 2 according to JIS Z 2201 so that the tensile direction matched the tube axis direction. A 2% tensile strain was applied as a prestrain and a heat treatment was performed while varying the heating temperature and holding time within the ranges of 100 to 250°C and 5 to 30 minutes to perform baking finishing. The tensile test specimens were taken at particular positions in the tube circumferential direction (eleven positions 30° spaced from each other in the circumferential direction while assuming the electric resistance welded portion to be 0°; the electric resistance welded portion is excluded). A tensile test was conducted on the bake-finished specimens. The 0.2% proof stress YS and the tensile strength TS after the baking finishing were determined and the yield ratio (=(YS/TS) $\times$ 100 (%)) after the baking finishing was calculated. The bake hardening value (BH value) was calculated as shown in Fig. 2 by determining the difference between the 0.2% proof stress after baking finishing and the strength after application of a 2% tensile strain. The maximum value and the minimum value of the BH value were determined from among the positions in the circumferential direction. YS and TS are each an arithmetic mean of the values at the positions in the circumferential direction. The results are shown in Table 5.

**[0060]** When the heating temperature of the heat treatment is less than 170°C, i.e., outside the range of the preferable baking finishing, a BH value of 100 MPa cannot be reliably achieved unless excessively long baking finishing is conducted without considering the decrease in productivity. The excessively long baking finishing refers to the baking finishing that takes more than 30 minutes. Even when the heating temperature is 170°C or more, a BH value of 100 MPa or more is not always achieved if the holding time is 5 minutes, i.e., less than 10 minutes, and a desired BH value cannot be stably achieved.

Reference Signs List

**[0061]**

1 strip
2 edge bend roll
3 center bend roll
4 cage roll
5 fin pass roll
6 welding means
7 squeeze roll
8 electric resistance welded tube
9 cutter
10 open tube

**[0062]**

[Table 1]

Table 1

| Steel No. | Chemical composition (mass%) | | | | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Al | N | Cu,Ni,Cr, Mo,Nb,Ti, W,B | Ca, REM | |
| A | 0.130 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | - | Example |
| B | 0.100 | 1.40 | 2.4 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | - | Example |
| C | 0.180 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0030 | - | - | Example |
| D | 0.140 | 0.80 | 2.3 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | - | Example |
| E | 0.130 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | Ti: 0.015,Nb: 0.021 | - | Example |
| F | 0.130 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0040 | Cr: 0.15,Mo: 0.10 | - | Example |
| G | 0.130 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | V:0.11 | - | Example |
| H | 0.130 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | Ni: 0.10,Cu: 0.10,B: 0.0015 | - | Example |
| I | 0.130 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | W:0.10 | Ca: 0.0030 | Example |
| J | 0.103 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | REM: 0.0030 | Example |
| K | 0.040 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | - | Comparative Example |
| L | 0.250 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | - | Comparative Example |
| M | 0.120 | 0.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | - | Comparative Example |
| N | 0.120 | 2.10 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | - | Comparative Example |
| O | 0.120 | 1.40 | 0.5 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | - | Comparative Example |
| P | 0.120 | 1.40 | 3.1 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | - | Comparative Example |
| Q | 0.130 | 1.40 | 2.2 | 0.018 | 0.0013 | 0.034 | 0.0020 | - | Ca: 0.0025 | Example |
| R | 0.135 | 1.40 | 2.2 | 0.0009 | 0.0010 | 0.048 | 0.0030 | - | - | Example |
| S | 0.145 | 1.43 | 2.1 | 0.015 | 0.0009 | 0.035 | 0.0038 | Ti:0.015 | - | Example |

[Table 2]

Table 2

| Steel tube No. | Steel No. | Transformation point (℃) | | | Hot-rolling process | | | | Cold-rolling process | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $Ac_1$ | $Ac_3$ | $Ar_3$ | Heating temperature (℃) | Finishing temperature (℃) | Coiling temperature (℃) | Thickness (mm) | Reduction (%) | Thickness (mm) |
| 1 | A | 740 | 899 | 859 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 2 | B | 738 | 908 | 868 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 3 | C | 740 | 886 | 846 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 4 | D | 722 | 870 | 830 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 5 | E | 740 | 899 | 859 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 6 | F | 743 | 903 | 863 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 7 | G | 740 | 899 | 859 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 8 | H | 739 | 898 | 858 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 9 | I | 741 | 901 | 861 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 10 | J | 740 | 899 | 859 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 11 | K | 740 | 932 | 892 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 12 | L | 740 | 871 | 831 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 13 | M | 711 | 858 | 818 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 14 | N | 761 | 934 | 894 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 15 | O | 758 | 902 | 862 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 16 | P | 731 | 902 | 862 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 17 | A | 740 | 899 | 859 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 18 | B | 738 | 908 | 868 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 19 | C | 740 | 886 | 846 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 20 | Q | 740 | 899 | 859 | 1200 | 900 | 700 | 3.0 | 40 | 1.8 |
| 21 | R | 740 | 898 | 858 | 1200 | 900 | 700 | 2.4 | 50 | 1.2 |
| 22 | S | 742 | 897 | 857 | 1250 | 910 | 580 | 3.6 | 50 | 1.8 |
| 23 | A | 740 | 899 | 859 | 1200 | 900 | 560 | 3 | 40 | 1.8 |
| 24 | A | 740 | 899 | 859 | 1200 | 900 | 600 | 3 | 40 | 1.8 |
| 25 | A | 740 | 899 | 859 | 1200 | 900 | 650 | 3 | 40 | 1.8 |

[Table 2 (continued)]

Table 2 (continued)

| Steel tube No. | Steel No. | Annealing process: Heating and cooling conditions: Heating temperature (°C) | Holding time (s) | Average cooling rate 1 (°C/s) | Quenching start temperature (°C) | Average cooling rate 2 (°C/s) | Cooling stop temperature (°C) | Tempering treatment: Heating temperature (°C) | Tube production process: Roll forming method | Tube size (mm): Outer diameter (mm φ) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | 860 | 500 | 11 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 2 | B | 860 | 500 | 12 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 3 | C | 860 | 500 | 15 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 4 | D | 860 | 500 | 15 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 5 | E | 860 | 500 | 19 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 6 | F | 860 | 500 | 19 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 7 | G | 860 | 500 | 15 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 8 | H | 860 | 500 | 15 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 9 | I | 860 | 500 | 10 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 10 | J | 860 | 500 | 10 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 11 | K | 860 | 500 | 11 | 680 | 1000 | RT | 200 | C B R | 48.6 | Comparative Example |
| 12 | L | 860 | 500 | 12 | 680 | 1000 | RT | 200 | C B R | 48.6 | Comparative Example |
| 13 | M | 860 | 500 | 11 | 680 | 1000 | RT | 200 | C B R | 48.6 | Comparative Example |
| 14 | N | 860 | 500 | 12 | 680 | 1000 | RT | 200 | C B R | 48.6 | Comparative Example |
| 15 | O | 860 | 500 | 15 | 680 | 1000 | RT | 200 | C B R | 48.6 | Comparative Example |
| 16 | P | 860 | 500 | 15 | 680 | 1000 | RT | 200 | C B R | 48.6 | Comparative Example |
| 17 | A | 860 | 500 | 15 | 680 | 1000 | RT | 200 | B D | 48.6 | Comparative Example |
| 18 | B | 860 | 500 | 15 | 680 | 1000 | RT | 200 | B D | 48.6 | Comparative Example |
| 19 | C | 860 | 500 | 15 | 680 | 1000 | RT | 200 | B D | 48.6 | Comparative Example |
| 20 | Q | 860 | 500 | 12 | 680 | 1000 | RT | 200 | C B R | 48.6 | Example |
| 21 | R | 830 | 500 | 6 | 680 | 1000 | RT | 150 | C B R | 48.6 | Comparative Example |
| 22 | S | 850 | 500 | 7 | 670 | 550 | RT | 355 | C B R | 48.6 | Comparative Example |
| 23 | A | 860 | 500 | 16 | 680 | 1100 | RT | 200 | C B R | 48.6 | Example |
| 24 | A | 860 | 500 | 16 | 680 | 1100 | RT | 200 | C B R | 48.6 | Example |
| 25 | A | 860 | 500 | 16 | 680 | 1100 | RT | 200 | C B R | 48.6 | Example |

Cooling rate 1: Cooling rate in the temperature range from the heat holding temperature to the temperature at the start of quenching
Cooling rate 2: Cooling rate from the temperature at the start of quenching to 200°C

[Table 2 (continued)]

Table 2 (continued)

| Steel tube No. | Steel No. | Transformation point(℃) | | Hot-rolling process | | | Cold-rolling process | |
|---|---|---|---|---|---|---|---|---|
| | | $Ac_1$ | $Ac_3$ | $Ar_3$ | Heating temperature | Finishing temperatur | Coiling temperature | Thickness (mm) | Reduction (%) | Thickness (mm) |
| 26 | A | 740 | 899 | 859 | 1200 | 900 | 700 | 3 | 40 | 1.8 |
| 27 | A | 740 | 899 | 859 | 1200 | 900 | 700 | 3 | 40 | 1.8 |
| 28 | A | 740 | 899 | 859 | 1200 | 900 | 700 | 3 | 40 | 1.8 |
| 29 | A | 740 | 899 | 859 | 1200 | 900 | 700 | 3 | 40 | 1.8 |
| 30 | A | 740 | 899 | 859 | 1200 | 900 | 700 | 3 | 40 | 1.8 |
| 31 | A | 740 | 899 | 859 | 1200 | 900 | 700 | 3 | 40 | 1.8 |
| 32 | A | 740 | 899 | 859 | 1200 | 900 | 700 | 3 | 40 | 1.8 |

Table 2 (continued)

| Steel tube No. | Steel No. | Annealing process | | | | | | | Tube production process | Tube size | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Heating and cooling conditions | | | | | Tempering treatment | | Roll forming method | Outer diameter (mmφ) | |
| | | Heating temperature (℃) | Holding time (s) | Average cooling rate 1 (℃/s) | Quenching start temperature (℃) | Average cooling rate 2 (℃/s) | Cooling stop temperature (℃) | Heating temperature (℃) | | | |
| 26 | A | 910 | 500 | 15 | 680 | 1000 | RT | 200 | —* | — | Comparative Example |
| 27 | A | 700 | 500 | 15 | 680 | 800 | RT | 200 | —* | — | Comparative Example |
| 28 | A | 860 | 500 | 15 | 580 | 600 | RT | 200 | —* | — | Comparative Example |
| 29 | A | 860 | 500 | 15 | 800 | 1000 | RT | 200 | —* | — | Comparative Example |
| 30 | A | 860 | 500 | 15 | 680 | 50 | RT | 200 | —* | — | Comparative Example |
| 31 | A | 860 | 500 | 15 | 680 | 1000 | RT | 100 | —* | — | Comparative Example |
| 32 | A | 860 | 500 | 15 | 680 | 1000 | RT | 350 | —* | — | Comparative Example |

*) —* : Tube was not produced

Cooling rate 1: Cooling rate in the temperature range from the heat holding temperature to the temperature at the start of quenching

Cooling rate 2: Cooling rate from the temperature at the start of quenching to 200°C

**[0063]** [Table 3]

Table 3

| Steel tube No. | Steel No. | Material for steel tube (cold-rolled annealed sheet) | | | | | | Properties of electric | |
|---|---|---|---|---|---|---|---|---|---|
| | | Structure | | Tensile characteristics | | | | Structure | |
| | | Type* | Martensite phase fraction (Vol%) | 0.2% proof stress YS (MPa) | Tensile strength TS (MPa) | Yield ratio YR (%) | Elongation E1 (%) | Type* | Martensite phase fraction (Vol%) |
| 1 | A | F+M | 52 | 870 | 1245 | 70 | 17 | F+M | 52 |
| 2 | B | F+M | 55 | 831 | 1190 | 70 | 18 | F+M | 55 |
| 3 | C | F+M | 58 | 880 | 1265 | 70 | 16 | F+M | 58 |
| 4 | D | F+M | 52 | 835 | 1201 | 70 | 17 | F+M | 52 |
| 5 | E | F+M | 51 | 877 | 1255 | 70 | 16 | F+M | 51 |
| 6 | F | F+M | 53 | 869 | 1245 | 70 | 16 | F+M | 53 |
| 7 | G | F+M | 52 | 839 | 1210 | 69 | 17 | F+M | 52 |
| 8 | H | F+M | 54 | 833 | 1189 | 70 | 16 | F+M | 54 |
| 9 | I | F+M | 55 | 840 | 1211 | 69 | 18 | F+M | 55 |
| 10 | J | F+M | 48 | 870 | 1245 | 70 | 18 | F+M | 48 |
| 11 | K | F+P+M | 10 | 591 | 845 | 70 | 22 | F+P+M | 10 |
| 12 | L | F+M | 65 | 933 | 1336 | 70 | 12 | F+M | 65 |
| 13 | M | F+M | 52 | 633 | 910 | 70 | 19 | F+M | 52 |
| 14 | N | F+M | 55 | 909 | 1311 | 69 | 11 | F+M | 55 |
| 15 | O | F+M | 45 | 770 | 1101 | 70 | 18 | F+M | 45 |
| 16 | P | F+M | 65 | 929 | 1340 | 69 | 12 | F+M | 65 |
| 17 | A | F+M | 52 | 883 | 1262 | 70 | 16 | F+M | 52 |
| 18 | B | F+M | 55 | 844 | 1210 | 70 | 16 | F+M | 55 |
| 19 | C | F+M | 58 | 901 | 1285 | 70 | 15 | F+M | 58 |
| 20 | Q | F+M | 52 | 875 | 1239 | 71 | 20 | F+M | 51 |
| 21 | R | F+M | 60 | 850 | 1227 | 69 | 16 | F+M | 60 |
| 22 | S | F+M | 70 | 860 | 1220 | 70 | 8 | F+M | 70 |
| 23 | A | F+M | 52 | 869 | 1243 | 70 | 18 | F+M | 52 |
| 24 | A | F+M | 53 | 858 | 1239 | 69 | 18 | F+M | 53 |
| 25 | A | F+M | 51 | 865 | 1226 | 71 | 19 | F+M | 51 |
| 26 | A | F+M | 80 | 955 | 1340 | 71 | 6 | Tube was not produced | |
| 27 | A | F+P | 0 | 630 | 756 | 83 | 18 | Tube was not produced | |
| 28 | A | F+M | 20 | 655 | 925 | 71 | 15 | Tube was not produced | |

(continued)

| Steel tube No. | Steel No. | Material for steel tube (cold-rolled annealed sheet) | | | | | | Properties of electric | |
|---|---|---|---|---|---|---|---|---|---|
| | | Structure | | Tensile characteristics | | | | Structure | |
| | | Type* | Martensite phase fraction (Vol%) | 0.2% proof stress YS (MPa) | Tensile strength TS (MPa) | Yield ratio YR (%) | Elongation E1 (%) | Type* | Martensite phase fraction (Vol%) |
| 29 | A | F+M | 80 | 945 | 1350 | 70 | 6 | Tube was not produced | |
| 30 | A | F+P | 0 | 628 | 765 | 82 | 18 | Tube was not produced | |
| 31 | A | F+M | 53 | 905 | 1245 | 73 | 8 | Tube was not produced | |
| 32 | A | F+M | 53 | 1001 | 1255 | 80 | 8 | Tube was not produced | |
| *)F: ferrite, M: martensite, B: bainite, P: pearlite | | | | | | | | | |

**[0064]** [Table 4]

Table 4

| Steel tube No | Steel No | Properties of electric resistance welded tubes | | | | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Tensile characteristics | | | | Properties after application of 2% prestrain → finishing | | | | | |
| | | 02% proof stress YS (MPa) | Tensile strength TS (MPa) | Yield ratio YR (%) | Elongation E1 (%) | 0.2% proof stress YS (MPa) | Tensile strength TS (MPa) | Yield ratio YR (%) | BH value | | |
| | | | | | | | | | Minimum | Maximum | |
| 1 | A | 1002 | 1265 | 79 | 14 | 1325 | 1355 | 98 | 110 | 125 | Example |
| 2 | B | 956 | 1210 | 79 | 15 | 1272 | 1301 | 98 | 112 | 122 | Example |
| 3 | C | 1027 | 1285 | 80 | 13 | 1345 | 1376 | 98 | 105 | 125 | Example |
| 4 | D | 951 | 1213 | 78 | 14 | 1280 | 1300 | 98 | 110 | 123 | Example |
| 5 | E | 1065 | 1276 | 83 | 12 | 1339 | 1365 | 98 | 112 | 115 | Example |
| 6 | F | 1023 | 1265 | 81 | 13 | 1321 | 1345 | 98 | 110 | 118 | Example |
| 7 | G | 1001 | 1233 | 81 | 14 | 1305 | 1333 | 98 | 112 | 120 | Example |
| 8 | H | 996 | 1206 | 83 | 13 | 1271 | 1296 | 98 | 115 | 122 | Example |
| 9 | I | 987 | 1236 | 80 | 14 | 1295 | 1321 | 98 | 115 | 125 | Example |
| 10 | J | 978 | 1265 | 77 | 15 | 1320 | 1346 | 98 | 112 | 118 | Example |
| 11 | K | 736 | 856 | 88 | 18 | 921 | 945 | 97 | 30 | 35 | Comparative Example |
| 12 | L | 1239 | 1356 | 91 | 8 | 1410 | 1443 | 98 | 110 | 125 | Comparative Example |
| 13 | M | 780 | 925 | 84 | 16 | 988 | 1016 | 97 | 115 | 125 | Comparative Example |
| 14 | N | 1121 | 1321 | 85 | 8 | 1375 | 1421 | 97 | 100 | 125 | Comparative Example |
| 15 | O | 905 | 1121 | 81 | 15 | 1201 | 1233 | 97 | 105 | 119 | Comparative Example |
| 16 | P | 1159 | 1353 | 86 | 8 | 1410 | 1441 | 98 | 102 | 125 | Comparative Example |
| 17 | A | 1246 | 1288 | 97 | 8 | 1350 | 1371 | 98 | 90 | 125 | Comparative |

(continued)

| Steel tube No | Steel No | Properties of electric resistance welded tubes | | | | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Tensile characteristics | | | | Properties after application of 2% prestrain → finishing | | | | | |
| | | 02% proof stress YS (MPa) | Tensile strength TS (MPa) | Yield ratio YR (%) | Elongation E1 (%) | 0.2% proof stress YS (MPa) | Tensile strength TS (MPa) | Yield ratio YR (%) | BH value | | |
| | | | | | | | | | Minimum | Maximum | |
| 18 | B | 1187 | 1235 | 96 | 8 | 1289 | 1315 | 98 | 90 | 135 | Comparative Example |
| 19 | C | 1256 | 1305 | 96 | 7 | 1356 | 1389 | 98 | 90 | 135 | Comparative Example |
| 20 | Q | 999 | 1258 | 79 | 17 | 1326 | 1352 | 98 | 112 | 125 | Example |
| 21 | R | 985 | 1233 | 80 | 12 | 1246 | 1356 | 92 | 56 | 65 | Comparative Example |
| 22 | S | 978 | 1239 | 79 | 5 | 1238 | 1345 | 92 | 45 | 56 | Comparative |
| 23 | A | 1003 | 1266 | 79 | 15 | 1328 | 1352 | 98 | 110 | 124 | Example |
| 24 | A | 989 | 1256 | 79 | 16 | 1321 | 1348 | 98 | 112 | 124 | Example |
| 25 | A | 979 | 1248 | 78 | 17 | 1329 | 1339 | 99 | 113 | 123 | Example |
| 26 | A | Tube was not produced | | | | | | | | | Comparative Example |
| 27 | A | Tube was not produced | | | | | | | | | Comparative Example |
| 28 | A | Tube was not produced | | | | | | | | | Comparative Example |
| 29 | A | Tube was not produced | | | | | | | | | Comparative Example |
| 30 | A | Tube was not produced | | | | | | | | | Comparative Example |
| 31 | A | Tube was not produced | | | | | | | | | Comparative Example |
| 32 | A | Tube was not produced | | | | | | | | | Comparative Example |

**[0065]** [Table 5]

Table 5

| Test specimen No. | Steel tube No. | Properties before baking finishing | | | Conditions of baking finishing * | | Properties after baking finishing | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.2% proof stress YS (MPa) | Tensile strength (MPa) | Yield ratio YR | Heating temperature (°C) | Holding time (min) | 0.2% proof stress YS (MPa) | Tensile strength (MPa) | Yield ratio YR | BH value (MPa) | |
| | | | | | | | | | | Minimum | Maximum |
| A1 | 1 | 870 | 1245 | 70 | 100 | 10 | 1184 | 1352 | 88 | 2 | 7 |
| A2 | 1 | 870 | 1245 | 70 | 100 | 15 | 1184 | 1354 | 87 | 2 | 8 |
| A3 | 1 | 870 | 1245 | 70 | 100 | 20 | 1185 | 1350 | 88 | 3 | 6 |
| A4 | 1 | 870 | 1245 | 70 | 100 | 25 | 1186 | 1355 | 88 | 4 | 8 |
| A5 | 1 | 870 | 1245 | 70 | 100 | 30 | 1187 | 1352 | 88 | 5 | 10 |
| A6 | 1 | 870 | 1245 | 70 | 150 | 10 | 1215 | 1350 | 90 | 33 | 105 |
| A7 | 1 | 870 | 1245 | 70 | 150 | 15 | 1232 | 1355 | 91 | 50 | 60 |
| A8 | 1 | 870 | 1245 | 70 | 150 | 20 | 1249 | 1360 | 92 | 67 | 79 |
| A9 | 1 | 870 | 1245 | 70 | 150 | 25 | 1265 | 1358 | 93 | 83 | 95 |
| A10 | 1 | 870 | 1245 | 70 | 150 | 30 | 1279 | 1355 | 94 | 97 | 115 |
| A11 | 1 | 870 | 1245 | 70 | 170 | 5 | 1275 | 1355 | 94 | 93 | 115 |
| A12 | 1 | 870 | 1245 | 70 | 170 | 10 | 1282 | 1354 | 95 | 100 | 110 |
| A13 | 1 | 870 | 1245 | 70 | 170 | 15 | 1322 | 1352 | 98 | 140 | 121 |
| A14 | 1 | 870 | 1245 | 70 | 170 | 20 | 1325 | 1355 | 98 | 110 | 125 |
| A15 | 1 | 870 | 1245 | 70 | 170 | 25 | 1329 | 1360 | 98 | 147 | 126 |
| A16 | 1 | 870 | 1245 | 70 | 170 | 30 | 1332 | 1365 | 98 | 150 | 132 |
| A17 | 1 | 870 | 1245 | 70 | 200 | 5 | 1281 | 1365 | 94 | 99 | 132 |
| A18 | 1 | 870 | 1245 | 70 | 200 | 10 | 1336 | 1357 | 98 | 154 | 167 |
| A19 | 1 | 870 | 1245 | 70 | 200 | 15 | 1335 | 1366 | 98 | 153 | 170 |
| A20 | 1 | 870 | 1245 | 70 | 200 | 20 | 1334 | 1362 | 98 | 152 | 165 |
| A21 | 1 | 870 | 1245 | 70 | 250 | 5 | 1281 | 1362 | 94 | 99 | 165 |

(continued)

| Test specimen No. | Steel tube No. | Properties before baking finishing | | | Conditions of baking finishing * | | Properties after baking finishing | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.2% proof stress YS (MPa) | Tensile strength (MPa) | Yield ratio YR | Heating temperature (°C) | Holding time (min) | 0.2% proof stress YS (MPa) | Tensile strength (MPa) | Yield ratio YR | BH value (MPa) | |
| | | | | | | | | | | Minimum | Maximum |
| A22 | 1 | 870 | 1245 | 70 | 250 | 10 | 1338 | 1365 | 98 | 156 | 165 |
| A23 | 1 | 870 | 1245 | 70 | 250 | 15 | 1340 | 1355 | 99 | 158 | 165 |
| A24 | 1 | 870 | 1245 | 70 | 250 | 20 | 1338 | 1358 | 99 | 156 | 170 |

*) Underlined conditions are outside the preferable conditions for baking finishing

## Claims

1. A high-strength electric resistance welded steel tube having a composition including, in terms of percent by mass,

C: 0.05 to 0.20% Si: 0.5 to 2.0%
Mn: 1.0 to 3.0% P: 0.1% or less
S: 0.01% or less Al: 0.01 to 0.1%
N: 0.005% or less, and the balance being Fe and unavoidable impurities,

and a structure which is a dual phase structure including a ferrite phase and a martensite phase, with a volume ratio of the martensite phase being 20 to 60%, wherein a tensile strength TS is 1180 MPa or more, an elongation El in a tube axis direction is 10% or more, and a yield ratio is less than 90%; and after application of a 2% prestrain and baking finishing that includes a heat treatment of 170°C × 10 min, a strength increase (BH value) is 100 MPa or more and a yield ratio is 90% or more.

2. The high-strength electric resistance welded steel tube according to Claim 1, wherein the composition further includes, in terms of percent by mass, at least one selected from Cu: 1.0% or less, Ni: 1.0% or less, Cr: 0.5% or less, Mo: 0.5% or less, Nb: 0.05% or less, Ti: 0.05% or less, W: 0.05% or less, and B: 0.0050% or less.

3. The high-strength electric resistance welded steel tube according to Claim 1 or 2, wherein the composition further includes, in terms of percent by mass, Ca: 0.0050% or less and/or REM: 0.0050% or less.

4. A method for producing a high-strength electric resistance welded steel tube, the method comprising a hot rolling process of hot-rolling a steel into a hot-rolled sheet; a cold-rolling process of pickling the hot-rolled sheet and cold-rolling the pickled hot-rolled sheet to prepare a cold-rolled sheet; an annealing process of annealing the cold-rolled sheet into a cold-rolled annealed sheet so as to prepare a material for a steel tube; and a tube production process of continuously forming the material for a steel tube into a substantially cylindrical open tube and electric-resistance-welding the open tube to prepare an electric resistance welded tube,
wherein the steel has a composition including, in terms of percent by mass,

C: 0.05 to 0.20% Si: 0.5 to 2.0%
Mn: 1.0 to 3.0% P: 0.1% or less
S: 0.01% or less Al: 0.01 to 0.1%
N: 0.005% or less, and the balance being Fe and unavoidable impurities,

in the hot-rolling process, the hot rolling is conducted at a finishing temperature equal to or higher than an $Ar_3$ transformation point and at a coiling temperature of 500 to 700°C to prepare the hot-rolled sheet,
in the annealing process, after soaking is performed at a temperature in a two-phase temperature region ranging from an $Ac_1$ transformation point to an $Ac_3$ transformation point, the sheet is cooled at an average cooling rate of 10°C/s or more to a temperature in the range of 600 to 750°C and then rapidly cooled at a cooling rate of 500°C/s or more from the temperature in the range of 600 to 750°C to room temperature, and then soaking is performed in the temperature range of 150 to 300°C,
the forming is performed by a roll forming method involving a cage roll method, and
the electric resistance welded tube has a tensile strength TS of 1180 MPa or more, an elongation El in a tube axis direction of 10% or more, and a yield ratio less than 90%, and exhibits, after application of a 2% prestrain and baking finishing that includes a heat treatment of 170°C × 10 min, a strength increase (BH value) of 100 MPa or more and a yield ratio of 90% or more.

5. The method for producing a high-strength electric resistance welded steel tube according to Claim 4, wherein the composition further includes, in terms of percent by mass, at least one selected from Cu: 1.0% or less, Ni: 1.0% or less, Cr: 0.5% or less, Mo: 0.5% or less, Nb: 0.05% or less, Ti: 0.05% or less, W: 0.05% or less, and B: 0.0050% or less.

6. The method for producing a high-strength electric resistance welded steel tube according to Claim 4 or 5, wherein the composition further includes, in terms of percent by mass, Ca: 0.0050% or less and/or REM: 0.0050% or less.

FIG. 1

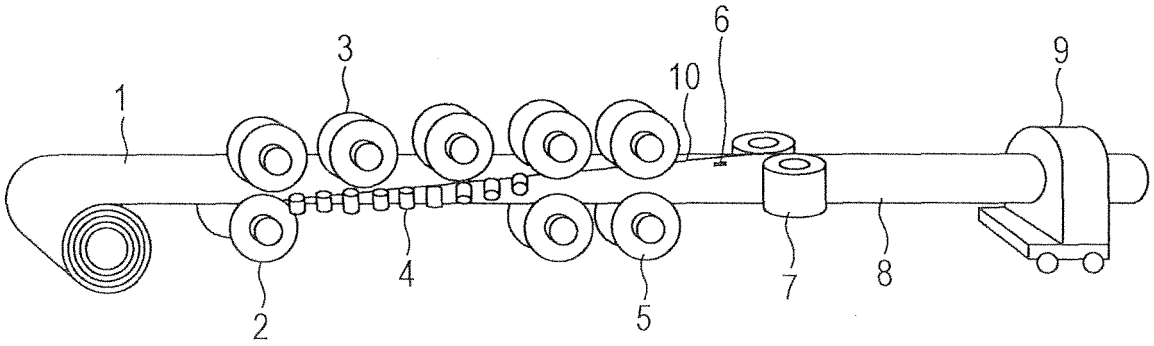
1
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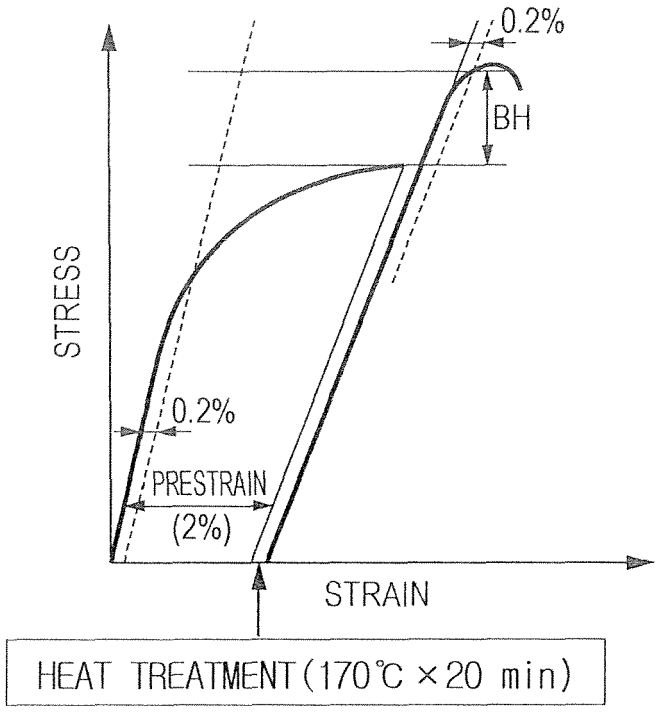
FIG. 2


0.2%
BH
STRESS
0.2%
PRESTRAIN
(2%)
STRAIN
HEAT TREATMENT (170℃ × 20 min)

**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2011/057928

A. CLASSIFICATION OF SUBJECT MATTER
*C22C38/06*(2006.01)i, *C22C38/58*(2006.01)i, *C21D8/02*(2006.01)i, *C21D9/46*(2006.01)i, *B21C37/08*(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)
C22C38/00-38/60, C21D8/00-8/04, C21D9/46-9/48, B21C37/08

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 | 1996-2011 |
| Kokai Jitsuyo Shinan Koho | 1971-2011 | Toroku Jitsuyo Shinan Koho | 1994-2011 |

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. |
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| A | JP 2006-299414 A (JFE Steel Corp.), 02 November 2006 (02.11.2006), claims; tables 1 to 3 (Family: none) | 1-6 |
| A | JP 2008-111162 A (JFE Steel Corp.), 15 May 2008 (15.05.2008), claims; tables 1, 2 (Family: none) | 1-6 |

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| Date of the actual completion of the international search<br>09 June, 2011 (09.06.11) | Date of mailing of the international search report<br>21 June, 2011 (21.06.11) |
| Name and mailing address of the ISA/<br>Japanese Patent Office<br><br>Facsimile No. | Authorized officer<br><br>Telephone No. |

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**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2011/057928

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
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## REFERENCES CITED IN THE DESCRIPTION

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