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(71) Applicant: **JFE Steel Corporation**
Tokyo, 100-0011 (JP)

(72) Inventors:
- **KAWABATA, Yoshikazu**
Tokyo 100-0011 (JP)
- **SAKAGUCHI, Masayuki**
Tokyo 100-0011 (JP)
- **SAKATA, Kei**
Tokyo 100-0011 (JP)

(74) Representative: **Grünecker, Kinkeldey,**
Stockmair & Schwanhäusser
Anwaltssozietät
Leopoldstrasse 4
80802 München (DE)

(54) HOLLOW MEMBER AND METHOD FOR MANUFACTURING SAME

(57) A method for manufacturing a hollow article having excellent durability is provided. In particular, an electric resistance welded steel pipe which is made from a steel sheet and in which the width of a low carbon layer is 2h (m) is subjected to a heat treatment that includes a quenching treatment in which the electric resistance welded steel pipe is heated to a heating temperature T (K) not lower than the Ac_3 transformation temperature at a heating rate V_h (K/s), held for a soaking time k (s), immediately cooled to a quenching start temperature Tq (K) at a primary cooling rate V_c(K/s), and then secondarily cooled (quenched). The heating rate V_h, the maximum heating temperature T, and the primary cooling rate V_c are adjusted so as to satisfy an inequality (herein C_0 (mass percent) is the C content (mass percent) of the steel sheet, t is the diffusion time (s), $t = 50 / V_h + 50 / V_c + k$, V_h is the heating rate (K/s), V_c is the primary cooling rate (K/s), k is the soaking time (s), D is the diffusion coefficient (m^2/s), D (m^2/s) = $D_0\exp(-Q / RT)$, Do is 4.7×10^{-5} (m^2/s), Q = 155 (kJ/mol·K), R = 8.31 (J/mol·K), and T is the maximum heating temperature (K)) and the quenching start temperature Tq is higher than the Ar_3 transformation temperature. This prevents the hardness as quenching of the electric resistance welded portion from being reduced and significantly increases the durability of the heat-treated article.

$$0.83 \leq 1-\left(1-0.09/C_0\right)\int_{-h}^{h}\exp\left(-y^2/\left(4Dt\right)\right)/\sqrt{4\pi Dt}dy$$

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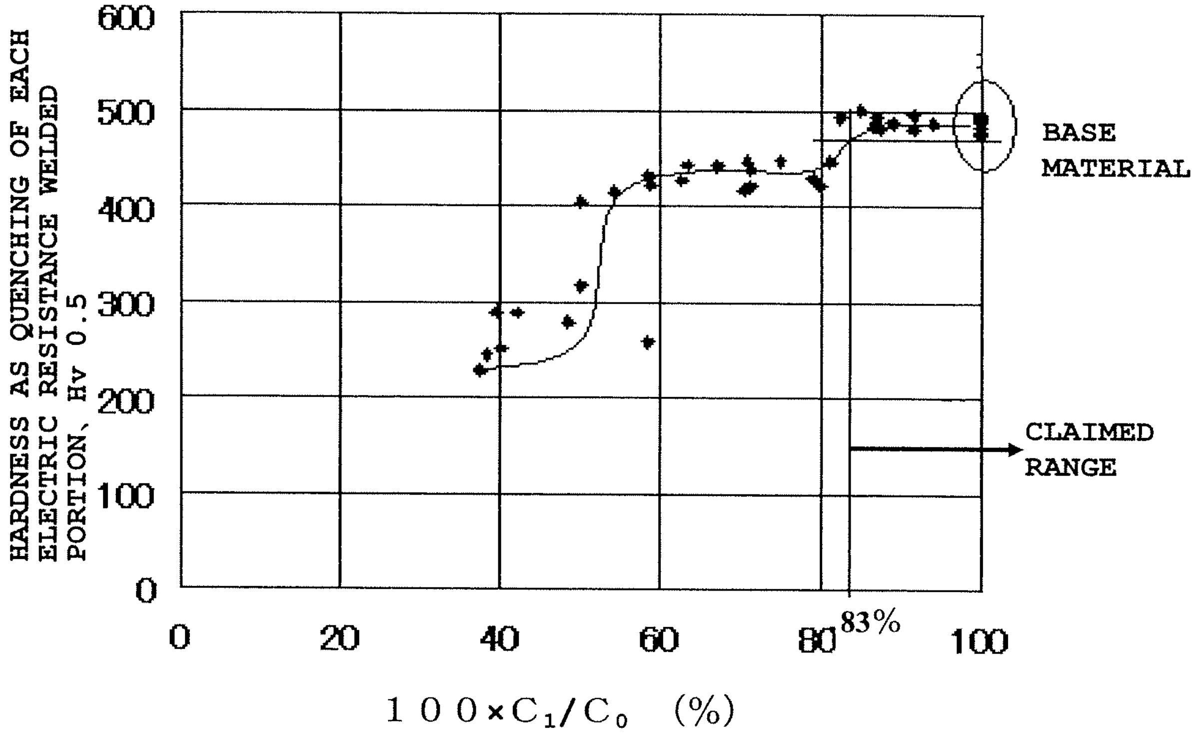
FIG.1


HARDNESS AS QUENCHING OF EACH ELECTRIC RESISTANCE WELDED PORTION, Hv 0.5
600
500
400
300
200
100
0
0
20
40
60
80
83%
100
BASE MATERIAL
CLAIMED RANGE
100×C1/C0 (%)

Description

Technical Field

[0001] The present invention relates to a hollow article made from an electric resistance welded steel pipe suitable for applications such as stabilizers and a method for manufacturing the same and particularly relates to the enhancement of the strength of an electric resistance-welded portion heat-treated by rapid heating for a short time or the like.

Background Art

[0002] In recent years, emission gas standards have been tightened in view of global environmental protection and therefore weight reduction in automobile bodies has been attempted for the purpose of improving fuel consumption. The replacement of solid-core parts with hollow parts has been recently attempted as a technique for reducing the weight of automobile bodies. This attempt is not an exception to stabilizers for preventing the rolling of the automobile bodies in the corners or improving the high-speed running stability. Solid-core parts made from bar steel are being replaced with hollow parts (hollow stabilizers) made from steel pipes, whereby weight reduction in automobile bodies is attempted.

[0003] Such hollow parts (hollow stabilizers) are usually manufactured in such a manner that seamless steel pipes or electric resistance welded steel pipes are cold-worked so as to have a desired shape and then subjected to thermal refining such as quenching or quenching and tempering. Since the electric resistance welded steel pipes are relatively inexpensive and are excellent in accuracy of dimension, the electric resistance welded steel pipes are widely used as materials for are hollow stabilizers. For example, Japanese Examined Patent Application Publication No. 1-58264 discloses a steel for electric resistance welded steel pipes for hollow stabilizers. The steel contains 0.35% or less C, 0.25% or less Si, 0.30% to 1.20% Mn, less than 0.50% Cr, N, O, Ti, and 0.0005% to 0.009% B and further contains 200 ppm or less Ca and/or Nb, the sum of the content of N and that of O being 0.0200% or less, the content of Ti being four to 12 times the sum of the content of N and that of O in the steel, the content of Nb being not greater than to four-tenths of the content of C. The C, Si, Mn, and Cr content is adjusted such that the ideal critical diameter D_1 is 1.0 in. or more. Furthermore, the C, Si, Mn, and Cr content is adjusted such that the carbon equivalent Ceq is 0.60% or less.

[0004] Japanese Examined Patent Application Publication No. 61-45688 discloses a method for producing a steel for electric resistance welded steel pipes for hollow stabilizers. The steel contains 0.35% or less C, 0.25% or less Si, 0.30% to 1.20% Mn, less than 0.50% Cr, N, O, Ti, and 0.0005% to 0.009% B and further contains 200 ppm or less Ca, the sum of the content of N and that of O being 0.0200% or less, the content of Ti being four to 12 times the sum of the content of N and that of O in the steel. The following slab is subjected to hot rolling and then coiled at a coiling temperature of 570˚C to 690˚C: a slab of the steel in which the C, Si, Mn, and Cr content is adjusted such that the D_1 value is 1.0 in. or more and furthermore, the C, Si, Mn, and Cr content is adjusted such that Ceq is 0.60% or less.

[0005] Japanese Unexamined Patent Application Publication No. 6-93339 discloses a method for manufacturing a high-strength, high-ductility electric resistance welded steel pipe usable for stabilizers. A technique disclosed in Japanese Unexamined Patent Application Publication No. 6-93339 is as follows: an electric resistance welded steel pipe made of a steel which contains 0.18% to 0.28% C, 0.10% to 0.50% Si, 0.60% to 1.80% Mn, 0.020% to 0.050% Ti, 0.0005% to 0.0050% B, and at least one of 0.20% to 0.50% Cr, 0.5% or less Mo, and 0.015% to 0.050% Nb and which further contains 0.0050% or less Ca is subjected to a normalizing treatment at a temperature of 850˚C to 950˚C and is then quenched, whereby the high-strength, high-ductility electric resistance welded steel pipe is manufactured.

[0006] Electric resistance welded steel pipes are widely used as materials for hollow parts because the electric resistance welded steel pipes are relatively inexpensive and are excellent in dimensional accuracy. Since further weight saving is recently aided and stresses applied to hollow parts are large, the techniques disclosed in Japanese Examined Patent Application Publication No. 1-58264, Japanese Examined Patent Application Publication No. 61-45688, and Japanese Unexamined Patent Application Publication No. 6-93339 are insufficient to secure the fatigue durability of electric resistance welded portions in some cases. This is because the hardenability of the electric resistance welded portions is insufficient. In the case where steel pipes are cold-bent so as to have a desired shape, rapidly heated for a short time by electrical heating, and then quenched, electric resistance welded portions thereof have reduced hardness after quenching (hereinafter referred to as hardness as quenching) and therefore articles sometimes have reduced fatigue durability. Electrical heating is a technique used in a step of quenching a stabilizer and is characterized in that electrical heating is capable of preventing decarburization even during heating in air because heating to 900˚C or higher, at which decarburization occurs in air, can be achieved in a short time of one minute or less. If decarburization occurs, a desired surface hardness is not obtained, which leads to a reduction in fatigue durability. Electrical heating, as used herein, refers to a heating technique in which the average heating rate from room temperature to a maximum heating temperature of 900˚C or higher is 10 ˚C/s or more and the time to hold 900˚C or higher is one minute or less.

Disclosure of Invention

[0007] The scope of the present invention is as described below.

(1) A method for manufacturing a hollow article having a desired high strength includes subjecting an electric resistance welded steel pipe which is made from a steel sheet and in which the width of a low carbon layer width is 2h (m) to a heat treatment that includes a quenching treatment in which the electric resistance welded steel pipe is heated to a heating temperature T (K) not lower than the Ac_3 transformation temperature at a heating rate V_h (K/s), held for a soaking time k (s), immediately cooled to a quenching start temperature Tq (K) at a primary cooling rate V_c(K/s), and then secondarily cooled and that further includes a tempering treatment. The heating rate V_h, the maximum heating temperature T, the soaking time k, and the primary cooling rate V_c are adjusted in the quenching treatment so as to satisfy the following inequality:

$$0.83 \leq 1-\left(1-0.09/C_0\right)\int_{-h}^{h} \exp\left(-y^2/(4Dt)\right)/\sqrt{4\pi Dt}\,dy \quad \ldots(1)$$

where C_0 (mass percent) is the C content (mass percent) of the steel sheet, t is the diffusion time (s), $t = 50 / V_h + 50 / V_c + k$, V_h is the heating rate (K/s), V_c is the primary cooling rate (K/s), k is the soaking time (s), D is the diffusion coefficient (m^2/s), $D = D_0\exp(-Q / RT)$, Do is 4.7×10^{-5} (m^2/s), Q = 155 (kJ/mol·K), R = 8.31 (J/mol·K), and T is the maximum heating temperature (K). The quenching start temperature Tq is higher than the Ar_3 transformation temperature. The formula giving D, which is the diffusion coefficient (m^2/s) is one quoted from the Japan Institute of Metals, Metal Data Book, 2nd ed., Maruzen, 1984, p. 26.
(2) In the hollow article-manufacturing method specified in Item (1), the steel sheet has a composition containing 0.15% to 0.40% C, 0.05% to 0.50% Si, 0.30% to 2.00% Mn, 0.01% to 0.10% Al, 0.001% to 0.04% Ti, 0.0005% to 0.0050% B, and 0.0010% to 0.0100% N on a mass basis, the remainder being Fe and unavoidable impurities, and Ti and N satisfy the inequality (N / 14) < (Ti / 47.9).
(3) The hollow article-manufacturing method specified in Item (2) further has a composition containing one or more selected from the group consisting of 1.0% or less Cr, 1.0% or less Mo, 1.0% or less W, 1.0% or less Ni, and 1.0% or less Cu on a mass basis in addition to the above composition.
(4) The hollow article-manufacturing method specified in Item (2) or (3) further has a composition containing one or more selected from the group consisting of 0.2% or less Nb and 0.2% or less V on a mass basis in addition to the above composition.
(5) The hollow article-manufacturing method specified in any one of Items (2) to (4) further has a composition containing 0.0050% or less Ca on a mass basis in addition to the above composition.
(6) A hollow article is manufactured by subjecting an electric resistance welded steel pipe of which a base material is a steel sheet and which includes an electric resistance welded portion including a low carbon layer with a width of 2h (m) to at least a quenching treatment. The ratio C_1/C_0 of the minimum C content C_1 of the electric resistance welded portion to the C content C_0 of a base material portion is 0.83 or more.
(7) In the hollow article specified in Item (6), the base material portion other than the electric resistance welded portion has a composition containing 0.15% to 0.40% C, 0.05% to 0.50% Si, 0.30% to 2.00% Mn, 0.01% to 0.10% Al, 0.001% to 0.04% Ti, 0.0005% to 0.0050% B, and 0.0010% to 0.0100% N on a mass basis, the remainder being Fe and unavoidable impurities, and Ti and N satisfy the inequality (N / 14) < (Ti / 47.9).
(8) The hollow article specified in Item (7) further has a composition containing one or more selected from the group consisting of 1.0% or less Cr, 1.0% or less Mo, 1.0% or less W, 1.0% or less Ni, and 1.0% or less Cu on a mass basis in addition to the above composition.
(9) The hollow article specified in Item (7) or (8) further has a composition containing one or more selected from the group consisting of 0.2% or less Nb and 0.2% or less V on a mass basis in addition to the above composition.
(10) The hollow article specified in any one of Items (7) to (9) further has a composition containing 0.0050% or less Ca on a mass basis in addition to the above composition.

Advantage

[0008] According to the present invention, the hardness as quenching of an electric resistance welded portion can be prevented from being reduced and a hollow article, having excellent durability, suitable for applications such as such as stabilizers can be readily and stably manufactured. This is particularly industrially advantageous.

Brief Description of Drawings

[0009]

Fig. 1 is a graph showing the relationship between the hardness as quenching HV0.5 of each electric resistance welded portion and the ratio C_1/C_0 of the minimum C content C_1 of the electric resistance welded portion to the C content C_0 of a corresponding one of base material portions.
Fig. 2 is a graph schematically showing a heat cycle pattern used in a quenching treatment.
Fig. 3 is an illustration showing an example of the measurement of the width of low carbon layers.
Fig. 4 is a graph showing the relationship between the diameter-reducing rolling reduction during reducing rolling and the width of bond after diameter reducing.
Fig. 5 is a graph showing the relationship between the fatigue durability and the ratio of the hardness of each electric resistance welded portion to the hardness of a corresponding one of base material portions.

Best Modes for Carrying Out the Invention

[0010] It is an object of the present invention to provide a method for manufacturing an electric resistance welded steel pipe for hollow article which solves the problems involved in the conventional techniques, in which the hardness as quenching of an electric resistance welded portion can be prevented from being reduced even if the electric resistance welded portion is subjected to a quenching treatment in such a manner that the electric resistance welded portion is rapidly heated for a short time and then quenched, and which has excellent fatigue durability.

[0011] In order to achieve the above object, the inventors have intensively investigated a factor that reduces the hardness as quenching of an electric resistance welded portion when an electric resistance welded steel pipe is subjected to a quenching treatment in such a manner that the electric resistance welded steel pipe is rapidly heated for a short time and then quenched. As a result, the inventors have found that electric resistance welded steel pipes include electric resistance welded portions including layers (low carbon layers) having a reduced amount of carbon as shown in the C concentration distribution, determined by EPMA (Electron Probe Micro-Analysis), shown in Fig. 3; the electric resistance welded portions cannot be recarburized to a carbon level not less than a desired level by rapid heating for a short time like electrical heating when the low carbon layers have an increased width; and therefore the electric resistance welded portions therefore have reduced hardenability and cannot be sufficiently secured in hardenability. The low carbon layers are unavoidable for electric resistance welding. The inventors have supposed that a low carbon layer is formed as described below.

(1) A welded portion is heated to a solid-liquid phase coexisting zone during electric resistance welding and C is concentrated in a liquid phase but diluted in a solid phase.
(2) The liquid phase, in which C is concentrated, is ejected out of an electric resistance welded portion because of upset during welding to create beads. Therefore, the solid phase, in which C is diluted, remains in the electric resistance welded portion and the low carbon layer is formed in the electric resistance welded portion.

[0012] The inventors have further performed investigations and have found that the hardness of a quenched electric resistance welded portion can be adjusted to a desired value and the fatigue durability of an article can be enhanced in such a manner that the heating rate, the attained maximum temperature, the soaking temperature, and the primary cooling rate to the quenching start temperature, which are among quenching conditions, are adjusted so as to satisfy a specific correlation relating to the width of a low carbon layer in an electric resistance welded portion and an amount of carbon sufficient to secure the hardness as quenching is thereby diffused from a base material to the electric resistance welded portion.

[0013] The inventors performed experiments. The experiment results on which the present invention is based are described below.

[0014] Hot-rolled Steel Sheet A having a composition shown in Table 1 was processed into steel pipe materials. The steel pipe materials were formed into open pipes with substantially a cylindrical shape. End portions of each of the open pipes were brought into contact with each other and then electrically welded by high-frequency resistance welding or further subjected to reducing rolling, whereby electric resistance welded steel pipes including low carbon layers with various widths (2h: 7 to 54 μm) were manufactured. The electric resistance welded steel pipes were subjected to a quenching treatment including a thermal cycle shown in Fig. 2, that is, the electric resistance welded steel pipes were heated to an attained maximum temperature (maximum heating temperature) T at a heating rate V_h, held for a soaking time k, immediately cooled to a quenching start temperature Tq at a primary cooling rate V_c, and then secondarily cooled (quenched).

[0015] After being subjected to the quenching treatment, the electric resistance welded steel pipes were measured for hardness, whereby the hardness as quenching thereof was determined. The measurement of hardness was performed in such a manner that a base material portion and an electric resistance welded portion were measured for Vickers hardness HV0.5 with a load of 500 g (a test force of 4.9 N) in the thickness direction thereof and the measurements were averaged, whereby the hardness as quenching of each portion was determined. In the experiments, the heating rate V_h, the attained maximum temperature T, and the primary cooling rate V_c were varied and the rate of secondary cooling (quenching) was constant (80 °C/s).

[0016] In other experiments, the diffusion of C due to the thermal cycle of the quenching treatment was investigated and the minimum C content C_1 of each quenched electric resistance welded portion was estimated by calculation. The following equation, which gives the content of C in a portion spaced from the center of a low carbon layer formed in an electric resistance welded portion of a steel pipe subjected to the thermal cycle of the quenching treatment at a distance x in the width direction of the low carbon layer, was used to estimate the C content C_1 of the electric resistance welded portion:

$$C_1(x) = C_0 - (C_0 - 0.09)\int_{-h}^{h} \exp\left(-(x-y)^2/(4Dt)\right)/\sqrt{4\pi Dt}\,dy \quad \cdots \text{(a)}$$

[0017] An integral term following the term (C_0 - 0.09) in Equation (a) shows how, when a location which is spaced from the center of a low carbon layer at a distance y in the width direction of the low carbon layer and which has a width dy has a certain initial C concentration and C is diffused from a base material portion to the low carbon layer after a time t elapsed, the C concentration of the location x varies. The initial C concentration of the low carbon layer formed during electric resistance welding was set such that the C content is constantly 0.09% from -h to +h in the width direction and follows a rectangular pattern. This is based on the fact that the C concentration of the low carbon layer formed during electric resistance welding is constantly about 0.09 mass percent regardless of the C concentration C_0 of a base material or welding conditions. Therefore, the C content of a location spaced from the center of a low carbon layer at a distance x in the width direction of the low carbon layer is determined from Equation (a) by integrating the integral term following the term (C_0 - 0.09) from -h to +h with respect to y in the integral term.

[0018] Herein, C_0 is the C content (mass percent) of a steel sheet, D is the diffusion coefficient (m^2/s), $D = D_0\exp(-Q / RT)$, D_0 is 4.7×10^{-5} (m^2/s), Q = 155 (kJ/mol·K), R = 8.31 (J/mol·K), T is the attained maximum temperature (maximum heating temperature) (K), t is the diffusion time (s), $t = 50 / V_h + 50 / V_c + k$, V_h is the heating rate (K/s), V_c is the primary cooling rate (K/s), and k is the soaking time (s). The equation defining the diffusion coefficient (m^2/s), which is represented by D, is one quoted from the Japan Institute of Metals, Metal Data Book, 2nd ed., Maruzen, 1984, p. 26. V_h and V_c are rates (K/s) determined at temperatures substantially not lower than 900°C. The minimum C content C_1 of the electric resistance welded portion corresponds to the value of $C_1(x)$ in Equation (a) when x = 0.

[0019] Fig. 1 shows the relationship between the measured average hardness HV0.5 and the ratio C_1/C_0 of the calculated minimum C content C_1 of each electric resistance welded portion to the C content C_0 of a corresponding one of steel sheets. Fig. 1 illustrates that the hardness (hardness as quenching) of the electric resistance welded portion can be regulated with the ratio C_1/C_0 and the reduction of the hardness as quenching thereof can be prevented by adjusting the ratio C_1/C_0 to 0.83 or more. Fig. 5 shows the relationship between the fatigue durability and the ratio of the hardness of each quenched and tempered electric resistance welded portion to the hardness of a corresponding one of base material portions. The fatigue durability is the fatigue strength determined by a fatigue test according to JIS Z 2273 under completely reversed torsion at a number of cycles of 10^6. Fig. 5 illustrates that an electric resistance welded portion with a hardness that is 86% or more of the hardness of the corresponding base material portion is not significantly reduced in fatigue strength.

[0020] Therefore, the adjustment of the ratio C_1/C_0 to 0.83 or more can prevent the fatigue durability of an electric resistance welded portion from being reduced due to a reduction in hardness as quenching. When the ratio C_1/C_0 is less than 0.83, the hardness as quenching is significantly reduced.

[0021] The present invention has been completed on the basis of these findings in addition to further investigations.

[0022] In the present invention, an electric resistance welded steel pipe, made from a steel sheet, including a low carbon layer with a width 2h (m) is used. The electric resistance welded steel pipe is manufactured in such a manner that the steel sheet is processed into materials; one of the materials is formed, preferably continuously formed, into an open pipe with substantially a cylindrical shape; and edge portions of the open pipe are brought into contact with each other and then electrically welded by high-frequency resistance welding. The electric resistance welded steel pipe includes an electric resistance welded portion that includes the low carbon layer, which has a width 2h (m). The width of the low carbon layer can be measured by various methods such as the analysis of C by EPMA (Electron Probe Micro-Analysis) as shown in the top of Fig. 3 and the measurement of the thickness of a white layer by nital etching (the middle of Fig. 3). For an electric resistance welded steel pipe untreated, heat-treated at a temperature of 950°C to lower than

1000°C for 10 s or less, heat-treated at a temperature of 900°C to lower than 950°C for one minute or less, heat-treated at a temperature of 800°C to lower than 900°C for two minutes or less, or heat-treated at a temperature lower than 800°C, a layer in which no segregation line is observed in an electric resistance welded portion, that is, the width of bond can be readily and clearly measured by performing metal flow etching as shown in the bottom of Fig. 3. When a metal flow etching process is usable, the bond width 2h determined by the metal flow etching process is hereinafter used as the low carbon layer width 2h.

[0023] In the present invention, quenching conditions are adjusted depending on the measured bond width (low carbon layer width) 2h so as to satisfy Inequality (1).

[0024] In the present invention, the electric resistance welded steel pipe used is preferably cold-worked so as to have a desired shape and then subjected to a heat treatment which includes a quenching treatment and which may further include a tempering treatment, whereby an article with a desired strength is obtained. The term "quenching treatment" as used herein refers to a rapid heating treatment for a short time as shown in Fig. 2, that is, a treatment in which the electric resistance welded steel pipe is heated to an attained maximum temperature (maximum heating temperature) T at a heating rate V_h, held for a soaking time k, immediately cooled to a quenching start temperature Tq at a primary cooling rate V_c, and then secondarily cooled (quenched). The term "rapid heating treatment for a short time" as used herein refers to a heating process the average heating rate from room temperature to an attained maximum temperature of 900°C or higher is 10 °C/s or more and the time to hold 900°C or higher is one minute or less. A particular heating technique is preferably electrical heating.

[0025] In the quenching treatment used herein, the heating rate V_h, the maximum heating temperature T, the soaking time k, and the primary cooling rate V_c are adjusted so as to satisfy the following inequality and the quenching start temperature Tq is adjusted to a temperature higher than the Ar_3 transformation temperature:

$$0.83 \le 1-\left(1-0.09/C_0\right)\int_{-h}^{h} \exp\left(-y^2/(4Dt)\right)/\sqrt{4\pi Dt}\,dy \quad \ldots (1)$$

wherein C_0 (mass percent) is the C content (mass percent) of a steel sheet, t is the diffusion time (s), t = 50 / V_h + 50 / V_c + k, V_h is the heating rate (K/s), V_c is the primary cooling rate (K/s), k is the soaking time (s), D is the diffusion coefficient (m^2/s), D = $D_0\exp(-Q / RT)$, Do is 4.7 $\times$ 10^{-5} (m^2/s), Q = 155 (kJ/mol·K), R = 8.31 (J/mol·K), and T is the maximum heating temperature (K).

[0026] The right side of Inequality (1) was obtained in such a manner that 0 was substituted for x in Equation (a) and both sides of Equation (a) were divided by C_0 representing the C content of the steel sheet. That is, the right side of Inequality (1) means that the ratio of the minimum C content $C_1(0)$ of an electric resistance welded portion to the C content C_0 of the steel sheet is 0.83 or more.

[0027] For a quenching treatment in which the heating rate V_h, the maximum heating temperature T, the soaking time k, and the primary cooling rate V_c do not satisfy Inequality (1), the C content of the electric resistance welded portion cannot be increased to a level sufficient to achieve a hardness as quenching substantially equal to the hardness of a base material portion; hence, the hardness of the electric resistance welded portion cannot be increased to a desired hardness as quenching and therefore a manufactured article has reduced durability. The soaking time k includes 0 s (no holding).

[0028] In the present invention, the quenching start temperature Tq in the quenching treatment is adjusted to a temperature higher than the Ar_3 transformation temperature of the electric resistance welded portion. When the quenching start temperature Tq is equal to or lower than the Ar_3 transformation temperature, the transformation of ferrite, bainite, and/or the like occurs prior to the start of secondary cooling (quenching) hence, the electric resistance welded portion cannot be transformed into a 100% martensite structure and a desired hardness as quenching or desired fatigue durability cannot be achieved. A value (Ac_3 transformation temperature) determined using a calculation formula below is used in place of the Ar_3 transformation temperature of the electric resistance welded portion. The Ac_3 transformation temperature shifts to a temperature higher than the Ar_3 transformation temperature upon the determination of the quenching start temperature Tq and is a safe-side value.

$$Ac_3 \text{ transformation temperature } (^\circ C) = 910 - 203(\sqrt{C}) - 15.2Ni + 44.7Si + 104V + 31.5Mo + 13.1W - (30Mn + 11Cr + 20Cu - 700P - 400Al - 120As - 400Ti)$$

wherein C, Ni, Si, V, Mo, W, Mn, Cr, Cu, P, Al, As, and Ti each represent the content (mass percent) of a corresponding one of elements.

[0029] The calculation formula defining the Ac_3 transformation temperature is one quoted from Koda, Leslie Tekkou Zairyougaku, Maruzen, 1985, p. 273.

[0030] Secondary cooling may be performed under cooling conditions capable of producing a 100% martensitic structure and depends on the composition of the steel sheet. The steel sheet, which has a composition below, is preferably cooled from the quenching start temperature Tq to room temperature at an average cooling rate of 30 ˚C/s or more and more preferably 80 ˚C/s or more. In view of manufacturing efficiency, secondary cooling is preferably water cooling, oil cooling, or the like.

[0031] In the case where conditions for heat-treating the electric resistance welded steel pipe have been set, the width of the low carbon layer, which is included in the electric resistance welded portion of the electric resistance welded steel pipe, needs to be adjusted to be equal to or less than the low carbon layer width 2h such that Inequality (1) is satisfied. In this case, the low carbon layer width 2h is determined from set quenching conditions and Inequality (1) so as to satisfy Inequality (1) for the set quenching conditions. An electric resistance welding condition, particularly the heat input, is preferably adjusted such that the low carbon layer width of the electric resistance welded portion is equal to or less than a determined value. When the bond width of the electric resistance welded portion is too small, a reduction in workability occurs in some cases. Therefore, it is important that the electric resistance welded portion is checked for workability by a bending test or the like. When the low carbon layer width 2h is too small to satisfy Inequality (1) and the untreated electric resistance welded portion has reduced workability, it is effective that after electric resistance welding is performed such that the bond width is greater than an appropriate value, the electric resistance welded steel pipe is subjected to diameter reducing such that the bond width is mechanically reduced. Diameter reducing is preferably performed by a drawing or punching process using a dice, a caliber rolling process, or the like. The temperature of diameter reducing may be cold, warm, or hot. Diameter reducing is preferably performed in such a manner that the electric resistance welded steel pipe is heated to a temperature of 950˚C to 1000˚C by induction heating and then subjected to reducing rolling at a reduction of diameter of 50% to 70% at a finish temperature of about 800˚C. As shown in Fig. 4, the bond width (low carbon layer width) 2h can be reduced by increasing the diameter-reducing rolling reduction during reducing rolling. In Fig. 4, the bond width 2h is used as the low carbon layer width. The low carbon layer width 2h is herein preferably 25 μm or less and more preferably 16 μm or less because the temperature achieved by conventional electrical heating is probably increased to 1000˚C and then reduced to 900˚C or lower in up to one minute for the purpose of preventing decarburization. Although it is naturally advantageous in view of heat treatment that the low carbon layer width is small, defects such as cold weld are likely to be caused in the electric resistance welded portion as described above if the heat input during electric resistance welding is reduced for the purpose of reducing the low carbon layer width. Therefore, the low carbon layer width as electric resistance welding is preferably 10 μm or more and more preferably 30 μm or more. When the low carbon layer width as electric resistance welding is greater than 30 μm, it is effective that the low carbon layer width is mechanically reduced to 25 μm or less and more preferably 16 μm or less in such a manner that the rolling reduction for diameter reducing is increased by reducing rolling or the like.

[0032] In the present invention, the tempering treatment may be performed subsequently to the quenching treatment for the purpose of increasing the toughness. The heating temperature in the tempering treatment is preferably within a range from 150˚C to 450˚C. When the heating temperature for tempering is lower than 150˚C, desired toughness cannot be achieved. When the heating temperature is higher than 450˚C, desired fatigue durability cannot be achieved because of a reduction in hardness.

[0033] In the present invention, the steel sheet, which is a material suitable for the electric resistance welded steel pipe, contains 0.15% to 0.40% C, 0.05% to 0.50% Si, 0.30% to 2.00% Mn, 0.01% to 0.10% Al, 0.001% to 0.04% Ti, 0.0005% to 0.0050% B, and 0.0010% to 0.0100% N and further contains one or more selected from the group consisting of 1.0% or less Cr, 1.0% or less Mo, 1.0% or less W, 1.0% or less Ni, and 1.0% or less Cu; and/or one or more selected from the group consisting of 0.2% or less Nb and 0.2% or less V; and/or 0.0050% or less Ca on a mass basis, the remainder being Fe and unavoidable impurities, and Ti and N satisfy the inequality $(N / 14) < (Ti / 47.9)$. The steel sheet is preferably a hot-rolled steel sheet. The term "steel sheet" as used herein covers any steel strip.

[0034] Reasons for limiting the composition thereof are described below. Mass percent is hereinafter simply represented by %.

C: 0.15% to 0.40%

[0035] C is a useful element that forms a solid solution to increase the strength of steel and precipitates in the form of a carbide or a carbonitride to increase the strength of tempered steel. In the present invention, in order to secure the desired strength of the steel sheet and the desired strength of a quenched article for hollow stabilizers and the like, the content of C needs to be 0.15% or more. When the content thereof is greater than 0.40%, the toughness is reduced after the quenching treatment. Therefore, the content of C is limited to a range from 0.15% to 0.40% and is preferably within a range from 0.20% to 0.35%.

Si: 0.05% to 0.50%

[0036] Si is an element acting as a deoxidizing agent. In order to obtain such an effect, the content thereof needs to be 0.05% or more. When the content is greater than 0.50%, the effect of deoxidation is saturated; hence, an advantage appropriate to the content cannot be expected, which is economically disadvantageous. Furthermore, inclusions are formed during electric resistance welding, which negatively affects the soundness of the electric resistance welded portion. Therefore, the content of S is limited to a range from 0.05% to 0.50% and is preferably within a range from 0.10% to 0.30%.

Mn: 0.30% to 2.00%

[0037] Mn is an element that forms a solid solution to increase the strength and hardenability of steel. In the present invention, in order to achieve a desired strength, the content thereof needs to be 0.30% or more. When the content is greater than 2.00%, retained austenite (y) is formed and the toughness is reduced after tempering. Therefore, the content of Mn is limited to a range from 0.30% to 2.00% and is preferably within a range from 0.30% to 1.60%.

Al: 0.01% to 0.10%

[0038] Al is a useful element that acts as a deoxidizing agent and has an effect of fixing N and an effect of securing the amount of solid solution B effective in increasing the hardenability. In order to obtain such effects, the content thereof needs to be 0.01% or more. When the content is greater than 0.10%, a large amount of inclusions are formed to cause a reduction in fatigue life in some cases. Therefore, the content of Al is limited to a range from 0.01% to 0.10% and is preferably within a range from 0.02% to 0.05%.

B: 0.0005% to 0.0050%

[0039] B is an element effective in increasing the hardenability of steel. B has the ability to strengthen grain boundaries and also has an effect of preventing quenching cracks. In order to obtain such an effect, the content thereof needs to be 0.0005% or more. When the content is greater than 0.0050%, the effect is saturated, which is economically disadvantageous. Furthermore, when the content is greater than 0.0050%, coarse inclusions containing B are produced to cause a reduction in toughness in some cases. Therefore, the content of B is limited to a range from 0.0005% to 0.0050% and is preferably within a range from 0.0010% to 0.0025%.

Ti: 0.001% to 0.04%

[0040] Ti is an element that has an effect of fixing N and an effect of securing the amount of solid solution B effective in increasing the hardenability. Ti precipitates in the form of a fine carbide, prevents grains from being coarsened during welding or heat treating, and contributes to an increase in toughness. In order to obtain such effects, the content thereof needs to be 0.001% or more. When the content is greater than 0.04%, a large amount of inclusions are formed to cause a reduction in toughness. Therefore, the content of Ti is limited to a range from 0.001% to 0.04% and is preferably within a range from 0.02% to 0.03%.

N: 0.0010% to 0.0100%

[0041] N is an element that combines with alloy elements in steel to produce nitrides and carbonitrides and contributes to secure the strength after tempering. In order to obtain such an advantage, the content thereof needs to be 0.0010% or more. When the content is greater than 0.0100%, the nitrides are coarsened to cause a reduction in toughness or fatigue life. Therefore, the content of N is limited to a range from 0.0010% to 0.0100%.

[0042] The content of Ti and that of N are within the above ranges and Ti and N satisfy the inequality $(N / 14) < (Ti / 47.9)$. When Ti and N do not satisfy this inequality, the amount of solid solution B is unstable during quenching, which is not preferred.

[0043] The above components are preferred fundamental components. In the present invention, one or more selected from an A Group, B Group, and C Group below may be contained in addition to the fundamental components. The following element or elements may be selectively contained as required:

A Group: one or more selected from 1.0% or less Cr, 1.0% or less Mo, 1.0% or less W, 1.0% or less Ni, and 1.0%

or less Cu;

B Group: one or more selected from 0.2% or less Nb and 0.2% or less V; and/or

C Group: 0.0050% or less Ca.

A Group: one or more selected from 1.0% or less Cr, 1.0% or less Mo, 1.0% or less W, 1.0% or less Ni, and 1.0% or less Cu

Cr, Mo, W, Cu, and Ni are elements having the ability to increase the hardenability of steel and one or more selected therefrom may be contained as required.

[0044] Cr has the ability to enhance the hardenability and the ability to form a fine carbide to increase the strength and contributes to secure desired strength. In order to obtain such effects, the content thereof is preferably 0.05% or more. When the content is greater than 1.0%, the effects are saturated, which is economically disadvantageous, and inclusions are likely to be formed during electric resistance welding, which negatively affects the soundness of the electric resistance welded portion. Therefore, the content of Cr is preferably limited to 1.0% or less and is more preferably within a range from 0.10% to 0.30%.

[0045] Mo has the ability to enhance the hardenability and the ability to form a fine carbide to increase the strength and contributes to secure desired strength. In order to obtain such effects, the content thereof is preferably 0.05% or more. When the content is greater than 1.0%, the effects are saturated, which is economically disadvantageous, and a coarse carbide is formed during electric resistance welding, thereby causing a reduction in toughness in some cases. Therefore, the content of Mo is preferably limited to 1.0% or less and is more preferably within a range from 0.10% to 0.30%.

[0046] W is an element that has the ability to enhance the hardenability and the ability to well balance the hardness and toughness as thermal refining. In order to obtain such effects, the content thereof is preferably 0.05% or more. When the content is greater than 1.0%, the effects are saturated, which is economically disadvantageous. Therefore, the content of W is preferably limited to 1.0% or less and is more preferably within a range from 0.10% to 0.30%.

[0047] Ni is an element that contributes to enhance the hardenability and the toughness. In order to obtain such effects, the content thereof is preferably 0.05% or more. When the content is greater than 1.0%, the effects are saturated, which is economically disadvantageous, and the workability is reduced. Therefore, the content of Ni is preferably limited to 1.0% or less and is more preferably within a range from 0.10% to 0.50%.

[0048] Cu is an element that is effective in enhancing the hardness and is effective in preventing delayed fracture.

[0049] In order to obtain such effects, the content thereof is preferably 0.05% or more. When the content is greater than 1.0%, the effects are saturated, which is economically disadvantageous, and the workability is reduced. Therefore, the content of Cu is preferably limited to 1.0% or less and is more preferably within a range from 0.10% to 0.30%.

B Group: one or more selected from 0.2% or less Nb and 0.2% or less V

Nb and V are elements that form carbides and contribute to enhance the strength. Nb and V may be selectively contained as required. In order to obtain such effects, the content of Nb and the content of V are preferably 0.01% or more. When the content of Nb and the content of V are greater than 0.2% respectively, the effects are saturated, which is economically disadvantageous. Therefore, the content of Nb and the content of V are preferably limited to 0.2% or less respectively.

C Group: 0.0050% or less Ca

Ca is an element that controls the morphology of inclusions such as sulfides to enhance the workability. Ca may be selectively contained as required. In order to obtain such an effect, the content thereof is preferably 0.0001% or more. When the content is greater than 0.0050%, the cleanness of steel is reduced. Therefore, the content of Ca is preferably limited to 0.0050% or less and is more preferably within a range from 0.0003% to 0.0010%.

[0050] The remainder other than the above components are Fe and unavoidable impurities. The unavoidable impurities are P, S, and O. A P content of 0.020% or less, an S content of 0.010% or less, and an O content of 0.005% or less are allowable.

[0051] P is an element that negatively affects the weld cracking resistance and the toughness. The content thereof is preferably adjusted to 0.020% or less and more preferably 0.015% or less.

[0052] S is present in steel in the form of a sulfide inclusion and is an element that reduces the workability, toughness, fatigue life of steel pipes and enhances the reheat crack sensitivity thereof. The content thereof is preferably adjusted to 0.010% or less and more preferably 0.005% or less for hollow stabilizer use.

[0053] O is present in steel in the form of an oxide inclusion and reduces the workability, toughness, fatigue life of steel pipes. Therefore, the content thereof is preferably adjusted to 0.005% or less and more preferably 0.002% or less for hollow stabilizer use.

[0054] The present invention is further described below with reference to an example.

[0055] A hollow article obtained by the above manufacturing method is manufactured in such a manner that an electric resistance welded steel pipe, made of a steel sheet, including an electric resistance welded portion having a low carbon layer with a width of 2h (m) is subjected to at least a quenching treatment. A base material portion (steel sheet) other than the electric resistance welded portion preferably satisfies the above composition. The hollow article according to the present invention has excellent durability and is characterized in that the ratio C_1/C_0 of the minimum C content C_1 of the electric resistance welded portion to the C content C_0 of the base material portion (steel sheet) is 0.83 or more. The following value is used: a value obtained in such a manner that the electric resistance welded portion of the hollow article is analyzed for C in the circumferential direction of the pipe by EPMA or chemical analysis.

[0056] The present invention is further described below with reference to examples.

Examples

[0057] Hot-rolled steel sheets having compositions shown in Table 1 were processed into materials. The materials were subjected to continuous cold forming, whereby open pipes with substantially a cylindrical shape were prepared. Edge portions of the open pipe were brought into contact with each other and then electrically welded by high-frequency resistance welding, whereby an electric resistance welded steel pipe (an outer diameter of 30 mmφ and a thickness of 6 mm) was prepared. Some of the hot-rolled steel sheets were processed into materials. These materials were subjected to continuous cold forming, whereby open pipes were prepared. These open pipes electrically welded, whereby base pipes having an outer diameter of 89 mmφ and a thickness of 6.2 mm were prepared. The base pipes were heated to 950˚C and then subjected to reducing rolling at a finish temperature of 800˚C, whereby steel pipes having an outer diameter of 30 mmφ and a thickness of 6 mm were prepared. For electric resistance welding, welding conditions were varied, whereby the width of bond (width of each low carbon layer) 2h was adjusted to various values as shown in Tables 2 and 3. The bond width (low carbon layer width) 2h was determined in such a manner that a specimen for microstructure observation was taken from each electric resistance welded steel pipe so as to include an electric resistance welded portion and then observed for microstructure. The untreated electric resistance welded steel pipes were subjected to a quenching treatment in a heat cycle pattern shown in Fig. 2 under conditions shown in Tables 2 and 3. Specimens for hardness measurement were taken from the untreated electric resistance welded steel pipes so as to include electric resistance welded portions and then subjected to hardness measurement, whereby base material portions and the electric resistance welded portions were measured for hardness as quenching. The electric resistance welded portion of each obtained electric resistance welded steel pipe was analyzed for C concentration in the circumferential direction of the pipe by EPMA at a position 100 μm away from the outer surface of the pipe, whereby the measured minimum C content C_1 (measured) was determined. The minimum C content C_1 of each electric resistance welded steel pipe subjected to the quenching treatment was calculated by substituting 0 for x in Equation (a) and then divided by the C content C_0 of the base material portion (steel sheet), whereby the ratio C_1/C_0 of calculated values and the ratio C_1/C_0 of measured values were calculated. The quenched steel pipes were tempered at 350˚C for 20 minutes, subjected to a torsion fatigue test, and then checked whether irregular cracks were present along the electric resistance welded portions. Such cracks along the electric resistance welded portions were represented by B × and other cracks were represented by A O.

[0058] Test methods were as described below.

(1) Microstructure observation

[0059] Specimens including the electric resistance welded portions were cut out of the obtained electric resistance welded steel pipes so as to have a cross section perpendicular to the axial direction of the pipes, polished, corroded with a metal flow etching solution (5% picric acid and a surface acting agent), and then observed for sectional structure with a light microscope (a magnification ratio of 400 times). The maximum width of a region (layer) in which no segregation line was observed in the sectional structure was measured, whereby the bond width (low carbon layer width) 2h was determined.

(2) Hardness measurement

[0060] Specimens for hardness measurement were taken from the obtained electric resistance welded steel pipes. The electric resistance welded portions and the base material portions were measured for Vickers hardness HV0.5 in the thickness direction thereof with a Vickers hardness meter (a load of 4.9 N). The outer surfaces were measured at a pitch of 0.2 mm. Obtained measurements were arithmetically averaged, whereby the hardness of the electric resistance welded portion and that of the base material portion of each steel pipe were determined.

(3) Torsion fatigue test

[0061] Specimens (a length of 250 mm in the axial direction of the pipes) for fatigue measurement were taken from the obtained electric resistance welded steel pipes having an outer diameter of 30 mmφ and a thickness of 6 mm and then subjected to a fatigue test according to JIS Z 2273 under completely reversed torsion. In the fatigue test, a stress τ of 380 MPa was applied to each of component A, B, and E materials and a stress τ of 470 MPa was applied to each of C and D materials.

[0062] Obtained results are shown in Tables 2 and 3.

[0063] In inventive examples (Tested Material Nos. 1 to 8, 10, and 33 to 35), the hardness as quenching of each electric resistance welded portion is not significantly low (electric resistance welded portion hardness/base material portion hardness: 0.98 or more) and there are no irregular cracks along the electric resistance welded portions in the fatigue test (as represented by A ○ in Tables 2 and 3). However, in comparative examples (Tested Material Nos. 9 and 11 to 32) that do not satisfy the low carbon layer width 2h specified herein or the appropriate range formula (the ratio C_1/C_0 is 0.83 or more) for heat-treating conditions, the hardness as quenching of each electric resistance welded portion is significantly low and there are irregular cracks along the electric resistance welded portions in the fatigue test (as represented by B × in Tables 2 and 3). In Tested Material No. 36 prepared from a component E material that does not satisfy the inequality $(N / 14) < (Ti / 47.9)$, which defines the component range specified herein, and that is an comparative example, although the low carbon layer width 2h specified herein and the appropriate range formula (the ratio C_1/C_0 is 0.83 or more) for heat-treating conditions are satisfied, the hardness as quenching of the base material portion and that of the electric resistance welded portion are significantly lower as compared to those of the A material, which has the same C content as that of the E material.

Table 1

Steels	Chemical components (mass percent)																	Fitness of relational formula* between N and Ti	Ac_3 transformation temperature (calculated) (˚C)
	C	Si	Mn	P	S	Al	N	Ti	B	Cr	Mo	Ni	Cu	Nb	V	Ca	O		
A	0.24	0.23	0.54	0.012	0.0020	0.015	0.0035	0.016	0.0023	0.29	-	-	-	-	-	0.0002	0.0010	Fit	823
B	0.19	0.39	1.58	0.011	0.0010	0.033	0.0032	0.013	0.0012	-	-	-	0.15	0.015	-	0.0002	0.0013	Fit	815
C	0.35	0.28	1.32	0.010	0.0009	0.033	0.0037	0.014	0.0026	-	-	-	-	-	-	0.0002	0.0006	Fit	789
D	0.35	0.28	1.32	0.010	0.0009	0.033	0.0037	0.014	0.0026	-	-	-	-	-	-	-	0.0006	Fit	789
E	0.24	0.22	0.53	0.012	0.0020	0.015	0.0048	0.009	0.0013	0.29	-	-	-	-	-	0.0002	0.0014	Not fit	819

(*) A relational formula between N and Ti: $N / 14 < Ti / 47.9$

Table 2

Tested Material Nos. ***	Steels	Width of low carbon layer (width of bond) 2h (μm)	Quenching conditions						Minimum C content of electric resistance welded portions C_1* (%)	C_1/C_0**	C_1(measured) /C_0	Hardness as quenching (Hv500g)			Results of fatigue test BX: cracks along electric resistance welded portion AO: other cracks	Remarks
			Heating rate Vh (°C/s)	Maximum heating temperature T (°C)	Soaking time k (s)	Primary cooling rate Vc (°C/s)	quenching start temperature Tq (°C)	Secondary cooling rate (°C/s)				Base material portions	Electric resistance welded portions	Hardness of electric resistance welded portion / hardness of base material portion		
1	A	7	15	920	0	10	850	80	0.20	0.85	0.87	483	500	1.03	A○	Inventive example
2	A	7	15	970	0	2	850	80	0.23	0.94	0.95	497	487	0.98	A○	Inventive example
3	A	7	15	970	0	5	850	80	0.22	0.92	0.93	493	496	1.01	A○	Inventive example
4	A	7	15	970	0	10	850	80	0.21	0.89	0.89	475	488	1.03	A○	Inventive example
5	A	7	15	970	0	20	850	80	0.21	0.87	0.88	492	494	1.00	A○	Inventive example
6	A	7	15	1020	0	10	850	80	0.22	0.92	0.92	490	482	0.98	A○	Inventive example
7	A	7	45	920	0	10	850	80	0.20	0.83	0.85	492	493	1.00	A○	Inventive example
8	A	7	45	970	0	10	850	80	0.21	0.88	0.89	479	482	1.01	A○	Inventive example
9	A	16	15	920	0	10	850	80	0.16	0.67	0.68	483	442	0.92	B×	Comparative example
10	A	16	15	970	0	2	850	80	0.21	0.87	0.89	497	484	0.97	A○	Inventive example
11	A	16	15	970	0	5	850	80	0.19	0.80	0.81	493	423	0.86	B×	Comparative example
12	A	16	15	970	0	10	850	80	0.18	0.75	0.77	475	448	0.94	B×	Comparative example
13	A	16	15	970	0	20	850	80	0.17	0.71	0.73	492	447	0.91	B×	Comparative example
14	A	16	15	1020	0	10	850	80	0.20	0.81	0.82	490	447	0.91	B×	Comparative example
15	A	16	45	920	0	10	850	80	0.15	0.63	0.65	492	427	0.87	B×	Comparative example
16	A	16	45	970	0	10	850	80	0.17	0.71	0.72	479	439	0.92	B×	Comparative example
17	A	25	15	920	0	10	850	80	0.13	0.54	0.56	483	415	0.86	B×	Comparative example
18	A	25	15	970	0	2	850	80	0.19	0.79	0.80	497	429	0.86	B×	Comparative example
19	A	25	15	970	0	5	850	80	0.17	0.70	0.72	493	417	0.85	B×	Comparative example
20	A	25	15	970	0	10	850	80	0.15	0.63	0.65	475	443	0.93	B×	Comparative example
21	A	25	15	970	0	20	850	80	0.14	0.58	0.61	492	432	0.88	B×	Comparative example
22	A	25	15	1020	0	10	850	80	0.17	0.71	0.72	490	421	0.86	B×	Comparative example

(*) Values (calculated values) obtained by substituting 0 for x in Equation (a).
(**) Values of the right side of Inequality (1).
(***) Tested Material Nos. 1 to 22 exhibited diameter reducing.

Table 3

Tested Material Nos. ***	Steels	Width of low carbon layer (width of bond) 2h (μm)	Quenching conditions						Minimum C content of electric resistance welded portions C_1* (%)	C_1/C_0**	C_1(measured) /C_0	Hardness as quenching (Hv500g)			Results of fatigue test BX: cracks along electric resistance welded portion AO: other cracks	Remarks
			Heating rate Vh (°C/s)	Maximum heating temperature T (°C)	Soaking time k (s)	Primary cooling rate Vc (°C/s)	quenching start temperature Tq (°C)	Secondary cooling rate (°C/s)				Base material portions	Electric resistance welded portions	Hardness of electric resistance welded portion / hardness of base material portion		
23	A	25	45	920	0	10	850	80	0.12	0.50	0.51	492	404	0.82	B×	Comparative example
24	A	25	45	970	0	10	850	80	0.14	0.59	0.60	479	424	0.88	B×	Comparative example
25	A	54	15	920	0	10	850	80	0.09	0.38	0.40	483	245	0.51	B×	Comparative example
26	A	54	15	970	0	2	850	80	0.14	0.58	0.60	497	259	0.52	B×	Comparative example
27	A	54	15	970	0	5	850	80	0.12	0.48	0.50	493	278	0.56	B×	Comparative example
28	A	54	15	970	0	10	850	80	0.10	0.42	0.44	475	289	0.61	B×	Comparative example
29	A	54	15	970	0	20	850	80	0.10	0.40	0.42	492	289	0.59	B×	Comparative example
30	A	54	15	1020	0	10	850	80	0.12	0.50	0.51	490	318	0.65	B×	Comparative example
31	A	54	45	920	0	10	850	80	0.09	0.38	0.40	492	227	0.46	B×	Comparative example
32	A	54	45	970	0	10	850	80	0.10	0.40	0.42	479	251	0.52	B×	Comparative example
33	B	7	45	970	1	10	850	80	0.16	0.84	0.85	470	470	1.00	A○	Inventive example
34	C	7	45	970	0	10	850	80	0.30	0.86	0.88	635	630	0.99	A○	Inventive example
35	D	7	45	970	0	10	850	80	0.30	0.86	0.87	633	633	1.00	A○	Inventive example
36	E	7	15	970	0	10	850	80	0.21	0.89	0.90	329	325	0.99	A○	Comparative example

(*) Values (calculated values) obtained by substituting 0 for x in Equation (a).
(**) Values of the right side of Inequality (1).
(***) Tested Material Nos. 1 to 22 exhibited diameter reducing.

Claims

1. A method for manufacturing a hollow article having a desired high strength and excellent durability, comprising subjecting an electric resistance welded steel pipe which is made from a steel sheet and in which the width of a low carbon layer width is 2h (m) to a heat treatment that includes a quenching treatment in which the electric resistance welded steel pipe is heated to a maximum heating temperature T (K) not lower than the Ac_3 transformation temperature at a heating rate V_h (K/s), held for a soaking time k (s), immediately cooled to a quenching start temperature Tq (K) at a primary cooling rate V_c(K/s), and then secondarily cooled and that further includes a tempering treatment, wherein the heating rate V_h, the maximum heating temperature T, the soaking time k, and the primary cooling rate V_c are adjusted in the quenching treatment so as to satisfy the following inequality and the quenching start temperature Tq is higher than the Ar_3 transformation temperature:

$$0.83 \le 1 - \left(1 - 0.09 / C_0\right) \int_{-h}^{h} \exp\left(-y^2 / \left(4Dt\right)\right) / \sqrt{4\pi Dt}\, dy \quad \cdots (1)$$

where C_0 is the C content (mass percent) of the steel sheet, t (s) = 50 / V_h + 50 / V_c + k, V_h is the heating rate (K/s), V_c is the primary cooling rate (K/s), k is the soaking time (s), D (m^2/s) = D_0exp(-Q / RT), Do is 4.7 $\times$ 10^{-5} (m^2/s), Q = 155 (kJ/mol·K), R = 8.31 (J/mol·K), and T is the maximum heating temperature (K).

2. The hollow article-manufacturing method according to Claim 1, wherein the steel sheet has a composition containing 0.15% to 0.40% C, 0.05% to 0.50% Si, 0.30% to 2.00% Mn, 0.01% to 0.10% Al, 0.001% to 0.04% Ti, 0.0005% to 0.0050% B, and 0.0010% to 0.0100% N on a mass basis, the remainder being Fe and unavoidable impurities, and Ti and N satisfy the inequality (N / 14) < (Ti / 47.9).

3. The hollow article-manufacturing method according to Claim 2, further having a composition containing one or more selected from the group consisting of 1.0% or less Cr, 1.0% or less Mo, 1.0% or less W, 1.0% or less Ni, and 1.0% or less Cu on a mass basis in addition to the above composition.

4. The hollow article-manufacturing method according to Claim 2 or 3, further having a composition containing one or more selected from the group consisting of 0.2% or less Nb and 0.2% or less V on a mass basis in addition to the above composition.

5. The hollow article-manufacturing method according to any one of Claims 2 to 4, further having a composition containing 0.0050% or less Ca on a mass basis in addition to the above composition.

6. A hollow article manufactured by subjecting an electric resistance welded steel pipe of which a base material is a steel sheet and which includes an electric resistance welded portion including a low carbon layer with a width of 2h (m) to at least a quenching treatment, wherein the ratio C_1/C_0 of the minimum C content C_1 of the electric resistance welded portion to the C content C_0 of a base material portion is 0.83 or more.

7. The hollow article according to Claim 6, wherein the base material portion other than the electric resistance welded portion has a composition containing 0.15% to 0.40% C, 0.05% to 0.50% Si, 0.30% to 2.00% Mn, 0.01% to 0.10% Al, 0.001% to 0.04% Ti, 0.0005% to 0.0050% B, and 0.0010% to 0.0100% N on a mass basis, the remainder being Fe and unavoidable impurities, and Ti and N satisfy the inequality (N / 14) < (Ti / 47.9).

8. The hollow article according to Claim 7, further having a composition containing one or more selected from the group consisting of 1.0% or less Cr, 1.0% or less Mo, 1.0% or less W, 1.0% or less Ni, and 1.0% or less Cu on a mass basis in addition to the above composition.

9. The hollow article according to Claim 7 or 8, further having a composition containing one or more selected from the group consisting of 0.2% or less Nb and 0.2% or less V on a mass basis in addition to the above composition.

10. The hollow article according to any one of Claims 7 to 9, further having a composition containing 0.0050% or less Ca on a mass basis in addition to the above composition.

FIG.1

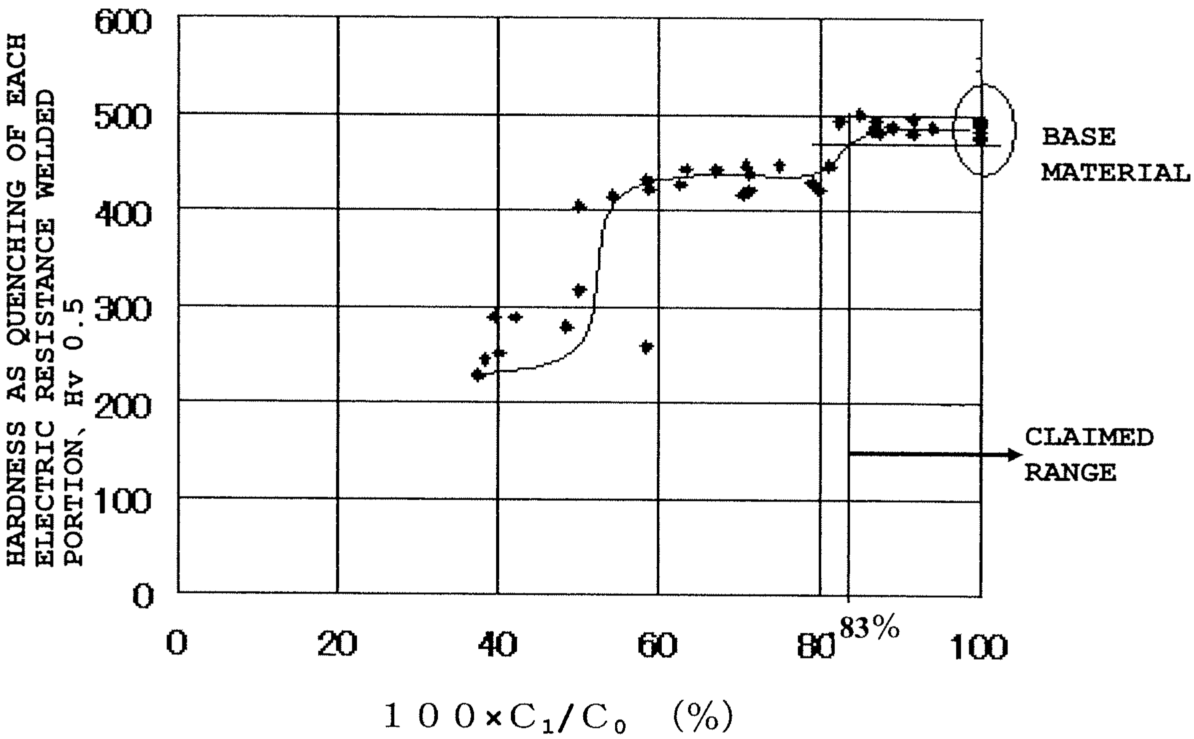

HARDNESS AS QUENCHING OF EACH ELECTRIC RESISTANCE WELDED PORTION, Hv 0.5
600
500
400
300
200
100
0
0
20
40
60
80
83%
100
BASE MATERIAL
CLAIMED RANGE
100×C1/C0 (%)

FIG.2

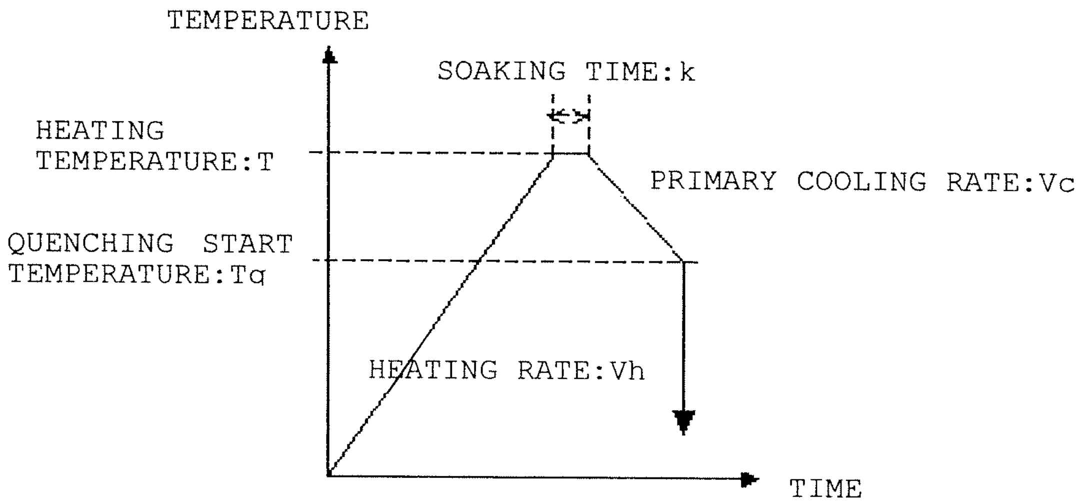

TEMPERATURE
SOAKING TIME:k
HEATING TEMPERATURE:T
PRIMARY COOLING RATE:Vc
QUENCHING START TEMPERATURE:Tq
HEATING RATE:Vh
TIME

FIG.3

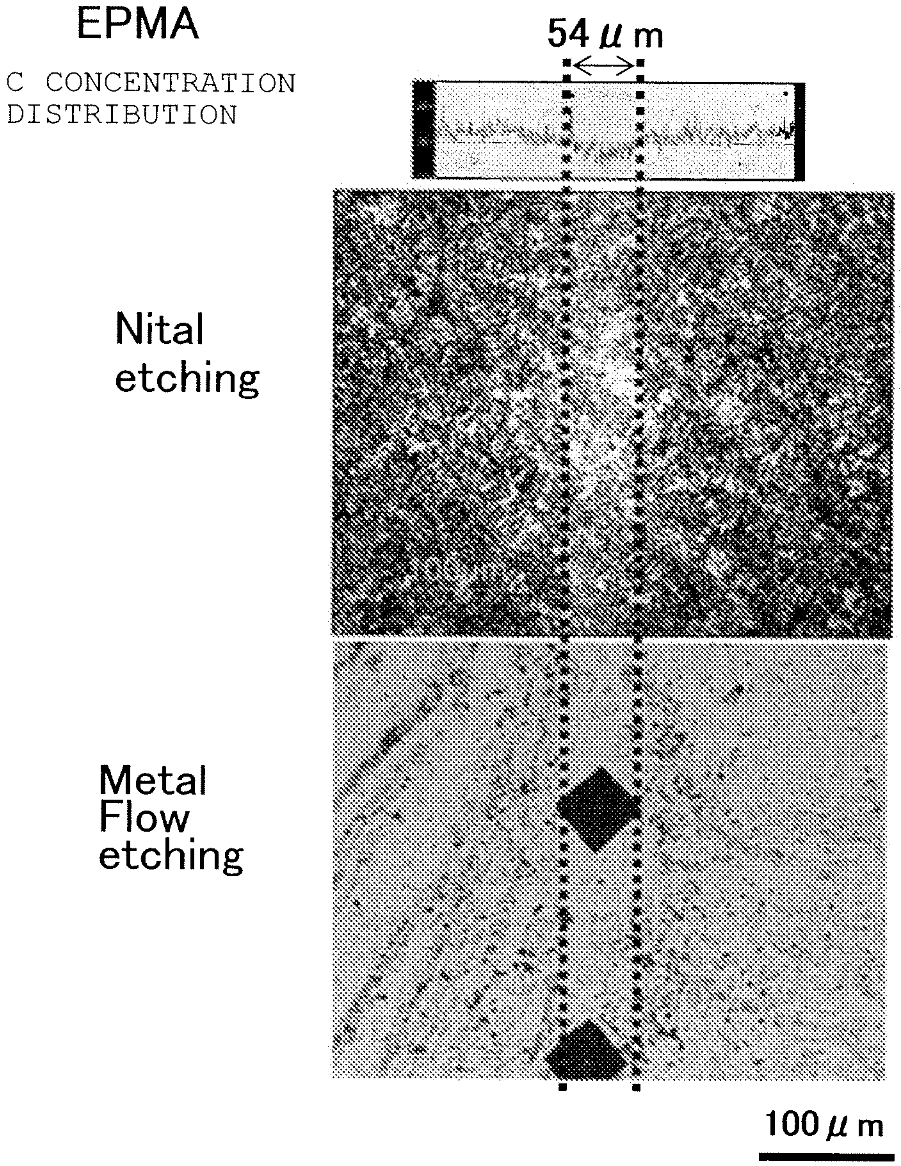

EPMA
C CONCENTRATION DISTRIBUTION
54 μm
Nital etching
Metal Flow etching
100 μm

FIG. 4

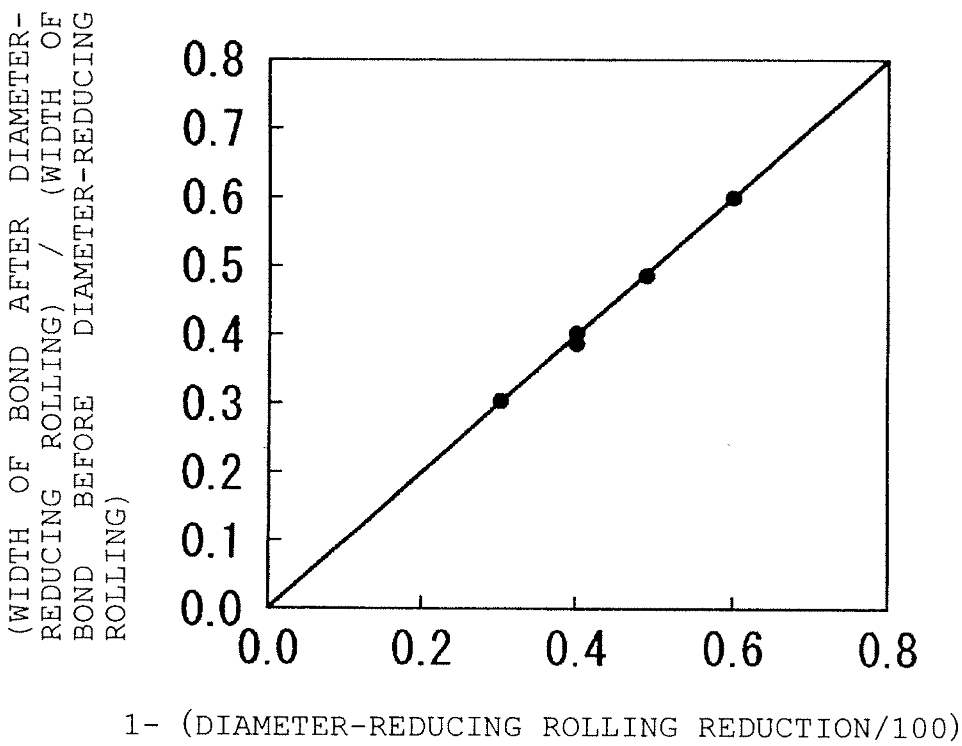
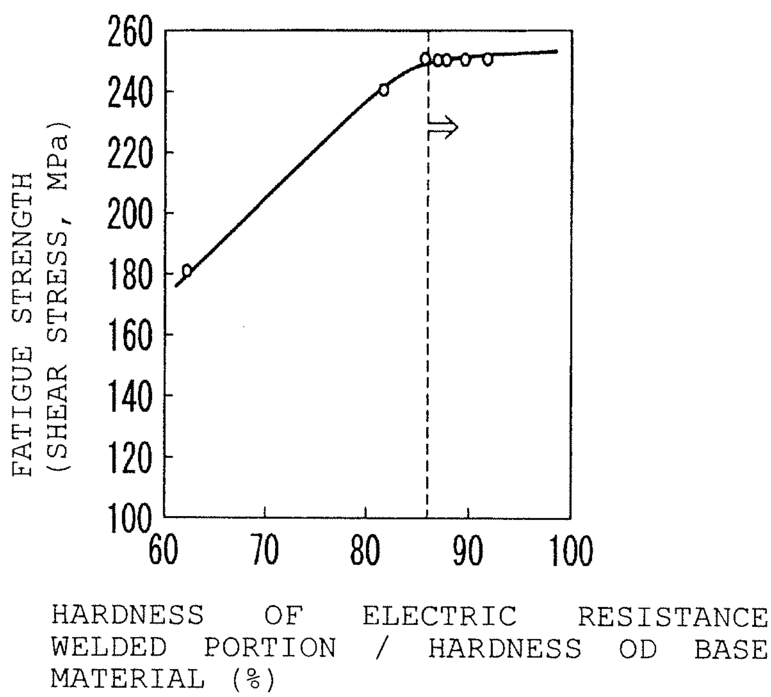

(WIDTH OF BOND AFTER DIAMETER-REDUCING ROLLING) / (WIDTH OF BOND BEFORE DIAMETER-REDUCING ROLLING)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.2
0.4
0.6
0.8
1- (DIAMETER-REDUCING ROLLING REDUCTION/100)

FIG. 5


FATIGUE STRENGTH (SHEAR STRESS, MPa)
260
240
220
200
180
160
140
120
100
60
70
80
90
100
HARDNESS OF ELECTRIC RESISTANCE WELDED PORTION / HARDNESS OD BASE MATERIAL (%)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2009/051148

A. CLASSIFICATION OF SUBJECT MATTER
C21D9/08(2006.01)i, *C21D9/50*(2006.01)i, *C22C38/00*(2006.01)i, *C22C38/14* (2006.01)i, *C22C38/58*(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)
C21D9/08, C21D9/50, C22C38/00-38/60, B60G21/055

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.
A	JP 59-153841 A (Nippon Steel Corp.), 01 September, 1984 (01.09.84), Full text (Family: none)	1-10
A	JP 4-135013 A (Kobe Steel, Ltd.), 08 May, 1992 (08.05.92), Full text & US 5180204 A	1-10
A	JP 2006-206999 A (JFE Steel Corp.), 10 August, 2006 (10.08.06), Full text (Family: none)	1-10

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

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

Date of the actual completion of the international search 15 April, 2009 (15.04.09)	Date of mailing of the international search report 28 April, 2009 (28.04.09)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2009/051148

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 2007-270349 A (Nippon Steel Corp.), 18 October, 2007 (18.10.07), Full text (Family: none)	1-10
A	JP 2007-56283 A (Nippon Steel Corp.), 08 March, 2007 (08.03.07), Full text (Family: none)	1-10
A	JP 2004-11009 A (Nippon Steel Corp.), 15 January, 2004 (15.01.04), Full text (Family: none)	1-10

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REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 1058264 A **[0003] [0006]**
- JP 61045688 A **[0004] [0006]**
- JP 6093339 A **[0005] [0006]**

Non-patent literature cited in the description

- Metal Data Book. Maruzen, 1984, 26 **[0007]**
- Japan Institute of Metals. Metal Data Book. Maruzen, 1984, 26 **[0018]**
- **Koda.** Leslie Tekkou Zairyougaku. Maruzen, 1985, 273 **[0029]**