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Motoyoshi et al.(10) **Pub. No.: US 2005/0034795 A1**(43) **Pub. Date: Feb. 17, 2005**(54) **HIGHLY IMPACT-RESISTANT STEEL PIPE
AND METHOD FOR PRODUCING THE
SAME**

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Hiroshige, Tokai-shi (JP)(51) **Int. Cl.⁷** **C21D 9/08**(52) **U.S. Cl.** **148/570; 148/320**(57) **ABSTRACT**Correspondence Address:
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A highly impact-resistant member has a round or square sectional shape, that is excellent in strength and toughness, does not undergo the deterioration of toughness in the vicinity of the welded portion, and a highly impact-resistant steel pipe has a tensile strength TS of 1,700 MPa or more and a yield ratio YR of 72% or less, the yield ratio being the ratio of a 0.1%-proof stress YS to a tensile strength TS (YS/TS). The toughness of the welded portion of the steel pipe is enhanced by controlling the Si amount in the steel of the steel pipe in the range from Mn/8-0.07 to Mn/8+0.07. The steel contains, in mass, 0.19 to 0.35% C, 0.10 to 0.30% Si, 0.5 to 1.60% Mn, not more than 0.025% P, not more than 0.01% S, 0.010 to 0.050% Al, 2 to 35 ppm B and 0.005 to 0.05% Ti as indispensable components.

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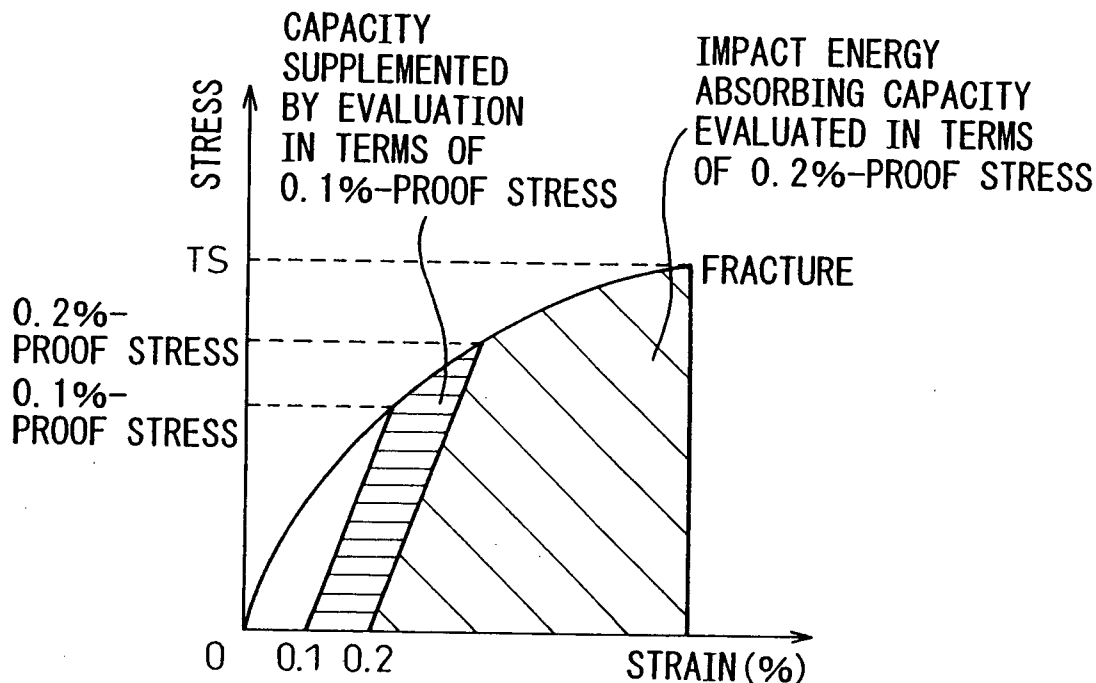


Fig.1

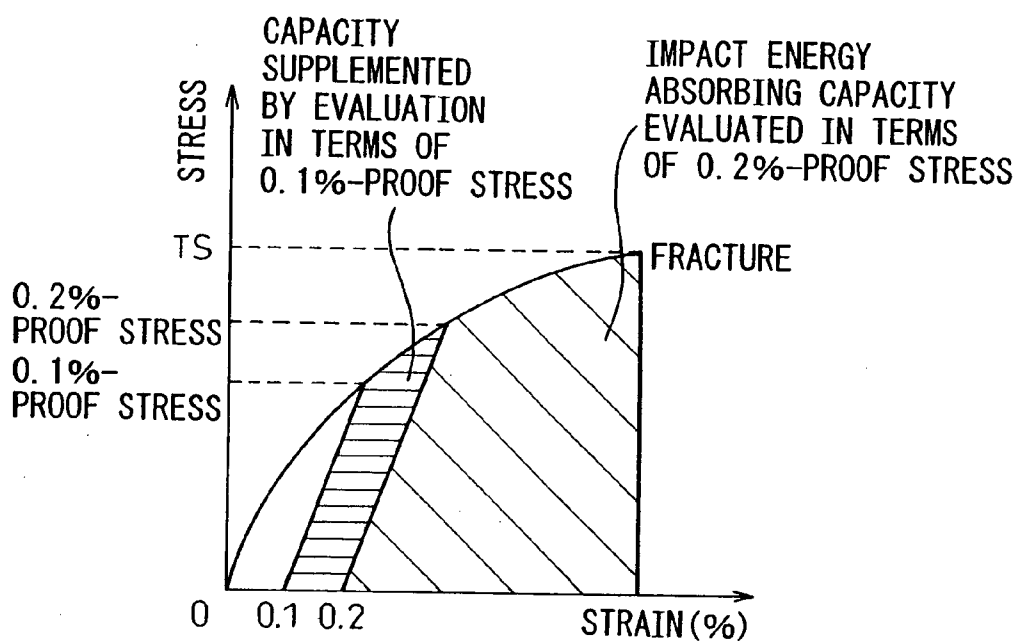


Fig.2

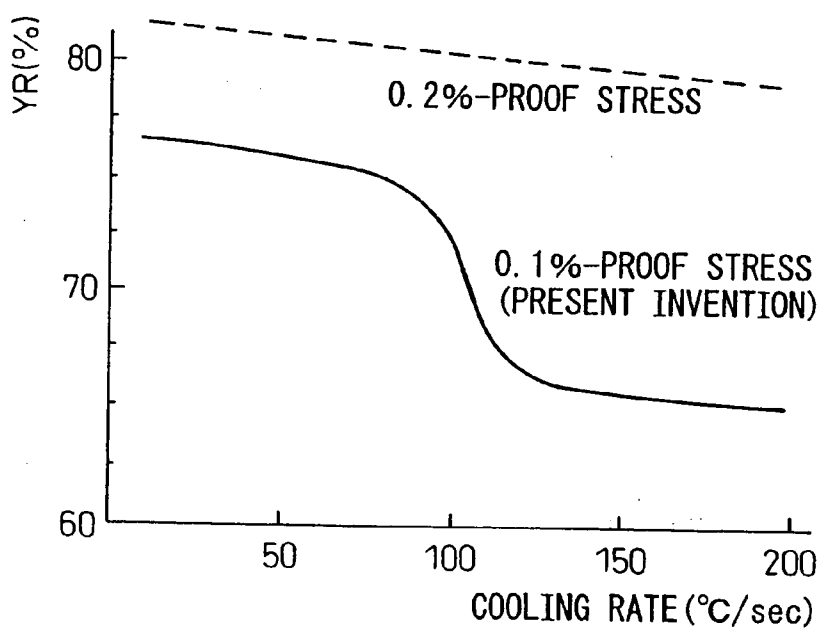


Fig.3

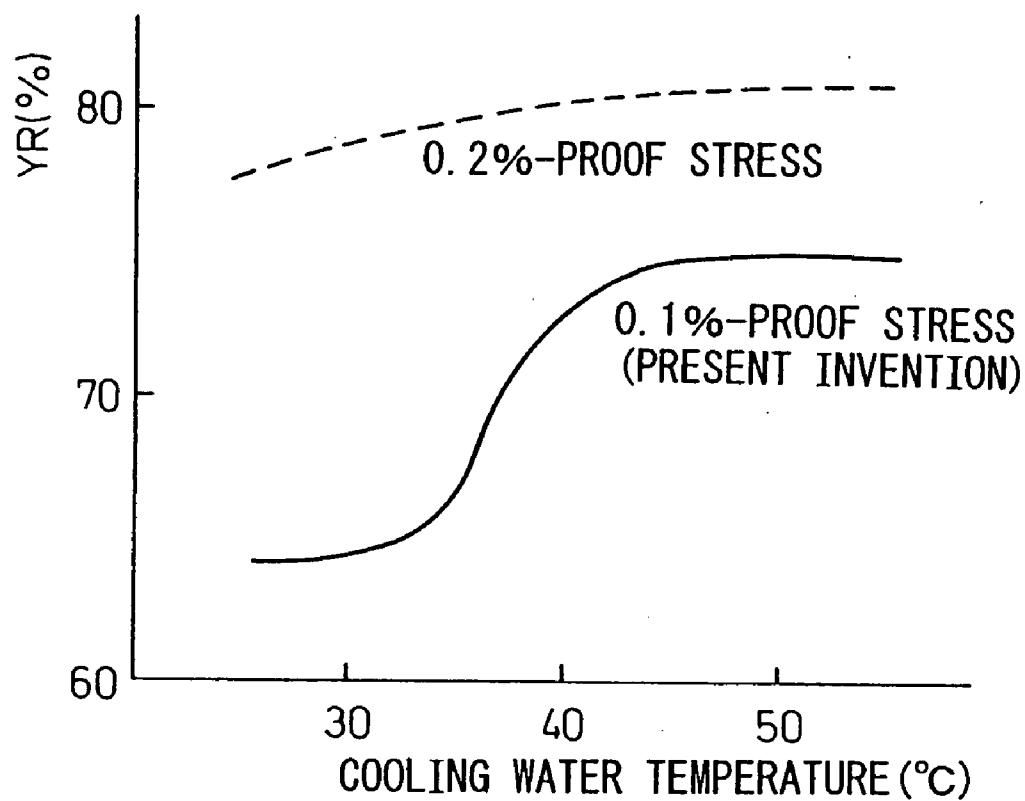


Fig.4

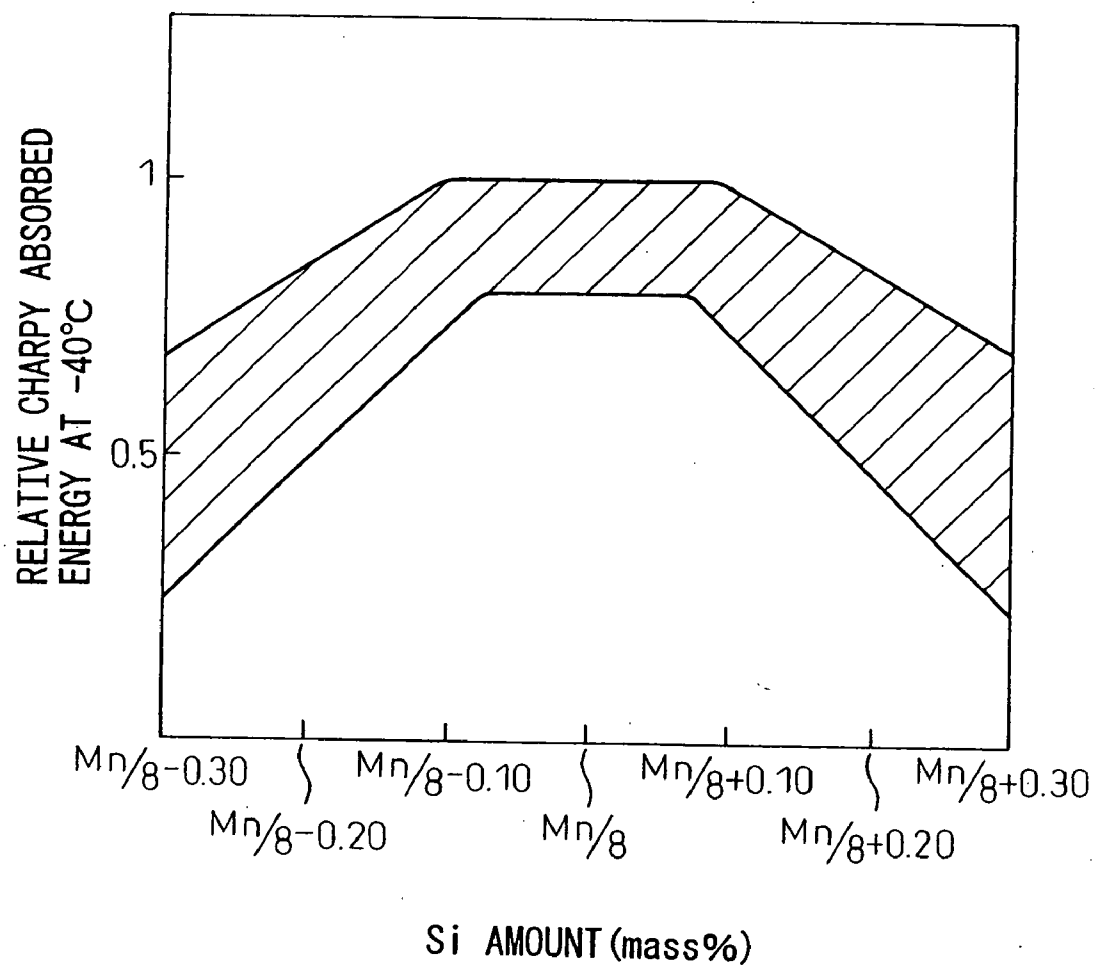
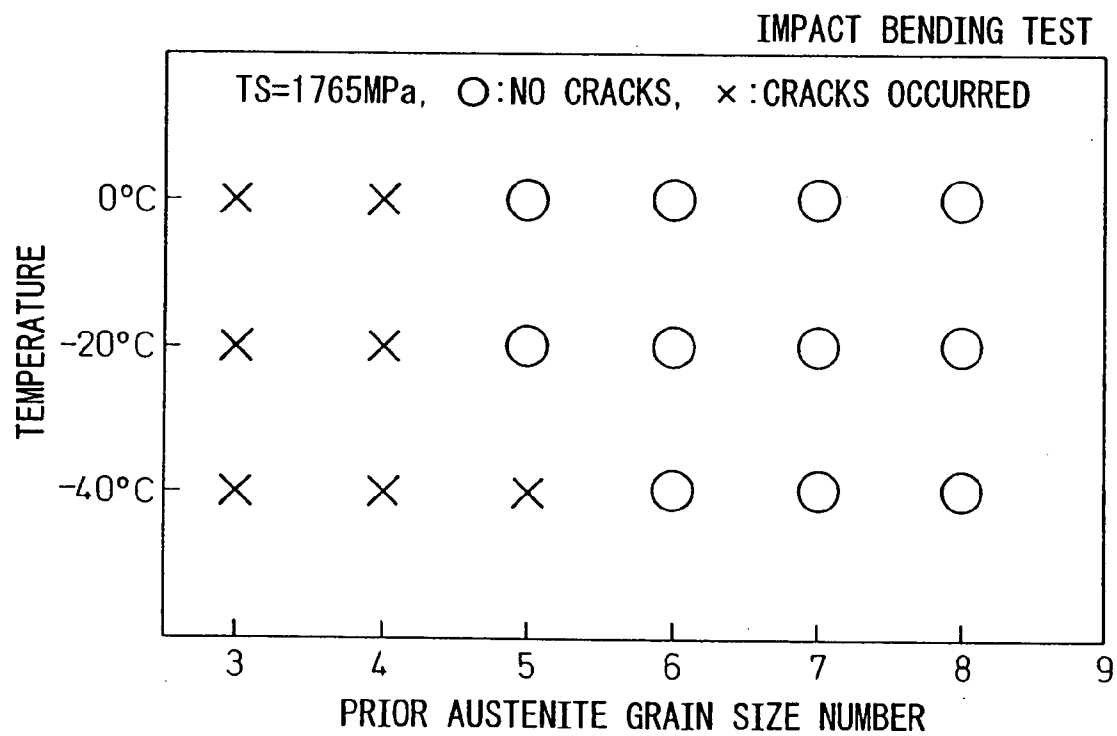


Fig.5



HIGHLY IMPACT-RESISTANT STEEL PIPE AND METHOD FOR PRODUCING THE SAME

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a highly impact-resistant steel pipe used as a member, such as a material for a door impact beam, a bumper, a bumper reinforcement or the like of an automobile, that requires an impact absorption energy, and a method for producing the steel pipe. Though the term "a steel pipe" is generally regarded as a steel pipe having a circular sectional shape, it is regarded as a steel pipe having a round or square sectional shape in this specification. Here, the round shape includes a circular shape, an elliptical shape, etc. and the square shape includes not only a polygonal shape such as a triangular shape, a tetragonal shape, a pentagonal shape, etc. but also an irregular sectional shape.

[0003] 2. Description of the Related Art

[0004] A high strength electric-resistance-welded steel pipe is mostly used for a member of a door impact beam disposed for absorbing the shock of a lateral collision of an automobile. Such a steel pipe is required to have an excellent impact absorbing capacity that is secured by a high tensile strength and a low proof stress and, when a steel pipe is one produced by electric-resistance-welding, the steel pipe is further required not to undergo the deterioration of strength and toughness at the welded portion. Such an impact absorbing capacity is expressed by a yield ratio defined by the ratio of a proof stress to a tensile strength. However, in general, the proof stress of a steel pipe increases as the tensile strength thereof increases and, therefore, the tensile strength and the yield ratio of a conventional steel pipe has been 1,500 to 1,600 MPa and 70 to 80%, respectively, at the least. For that reason, a steel pipe having a higher strength and a lower yield ratio has been desired for further promoting weight reduction and improving collision safety.

[0005] Meanwhile, a proof stress has so far been generally obtained by measuring a stress imposing a permanent strain of 0.2% on a test piece as it is stipulated in JIS and a yield ratio has been calculated on the basis of the 0.2%-proof stress. FIG. 1 is a graph schematically showing the stress-strain curve of a steel and the impact energy that can be absorbed by the deformation of an impact absorbing member at the time of collision is represented by the area of the hatched portion. As a steel pipe has so far been evaluated by a 0.2%-proof stress, an impact absorbing member has been designed with the area of the portion hatched by the oblique lines sloping to the right regarded as an impact energy absorbing capacity. On the contrary, according the research by the present inventors, it has been clarified that, in the case of a steel material not having a clearly visible yield point, namely having a stress-strain curve with a sloping shoulder, a considerable amount of impact energy is absorbed before a permanent strain of 0.2% is imposed on the steel pipe at the time of collision as shown in FIG. 1 and therefore the impact absorbing capacity of the steel material has been underestimated when it is evaluated by a yield ratio calculated on the basis of a 0.2%-proof stress stipulated in JIS.

[0006] Needless to say, an electric-resistance-welded portion and the vicinity thereof are also required to have not

only the strength but also the toughness that governs an impact energy absorbing capacity. To meet the requirements, various developments have been used in an effort to improve those properties as shown in Japanese Unexamined Patent Publication No. H7-18374. However, most electric-resistance-welded steel pipes tend to undergo deterioration of strength and toughness in the vicinity of the electric-resistance-welded portions because the steel pipes are produced by electric-resistance-welding.

SUMMARY OF THE INVENTION

[0007] The object of the present invention is, by solving the aforementioned conventional problems, to provide: a highly impact-resistant steel pipe having the material properties of a higher strength and a lower yield ratio than a conventional steel pipe, not undergoing the deterioration of toughness in the vicinity of an electric-resistance-welded portion in the case of an electric-resistance-welded steel pipe, and further having an ultra-low weight and a high collision safety; and a method for producing the steel pipe.

[0008] A highly impact-resistant steel pipe according to the claim 1 of the present invention that is established for solving the aforementioned problems is characterized in that: the tensile strength (hereunder referred to as TS) of the steel pipe is 1,700 MPa or more; and the yield ratio (hereunder referred to as YR) thereof, the yield ratio being the ratio of the 0.1%-proof stress (hereunder referred to as YS) to the tensile strength TS (YS/TS), is 72% or less. Likewise, TS is 1,800 MPa or more and YR is 70% or less in the claim 2 of the present invention, TS is 1,900 MPa or more and YR is 68% or less in the claim 3 thereof, and TS is 2,000 MPa or more and YR is 66% or less in the claim 4 thereof. Here, it is preferable that the dislocation density of a steel pipe after a tensile test according to JIS is in the range from 10^{10} to $10^{14}/\text{mm}^{-2}$.

[0009] Further, the present inventors: measured the properties of Charpy absorbed energy in the vicinity of electric-resistance-welded portions in an attempt to solve the aforementioned problems; found that oxides containing Si and Mn remained on the fractured surface at a portion where Charpy absorbed energy decreased and those components were one of the causes of the deterioration of toughness; and confirmed that the deterioration of toughness in the vicinity of an electric-resistance-welded portion could be prevented when a specific relationship between Si and Mn, namely according to the expression $\text{Mn}/8-0.07 \leq \text{Si} \leq \text{Mn}/8+0.07$, was secured.

[0010] The gist of the claim 5 of the present invention is a highly impact-resistant electric-resistance-welded steel pipe characterized by having a high strength of 1,700 MPa or more in tensile strength and being produced by controlling the Si amount in the steel of the steel pipe in the range from $\text{Mn}/8-0.07$ to $\text{Mn}/8+0.07$.

[0011] A highly impact-resistant steel pipe according to the present invention: preferably contains, in mass, 0.19 to 0.35% C, 0.1 to 0.3% Si, 0.5 to 1.6% Mn, not more than 0.025% P, not more than 0.02% S, 0.010 to 0.050% Al, 2 to 35 ppm B, and 0.005 to 0.05% Ti as indispensable components; and may further contain, in mass, arbitrary components selected from among the group of 0.005 to 0.050% Nb, 0.005 to 0.070% V, 0.005 to 0.5% Cu, 0.005 to 0.5% Cr, 0.1 to 0.5% Mo, 0.1 to 0.5% Ni, not more than 0.01% Ca, and

not more than 0.1% rare earth metals (REMS). Further, it is preferable that 95% or more of the microstructure of the steel pipe is transformed into martensite by induction hardening and the prior austenite grain size number of the steel pipe is #6 or more. Here, the sectional shape includes both a round shape and a square shape.

[0012] Further, a method for producing a highly impact-resistant steel pipe according to the present invention is characterized in that said steel pipe containing, in mass, 0.19 to 0.35% C, 0.1 to 0.3% Si, 1.0 to 1.6% Mn, not more than 0.025% P, not more than 0.02% S, 0.010 to 0.050% Al, 2 to 35 ppm B, and 0.005 to 0.05% Ti as indispensable components, and arbitrary components selected from among the group of 0.005 to 0.050% Nb, 0.005 to 0.070% V, 0.005 to 0.5% Cu, 0.005 to 0.5% Cr, 0.1 to 0.5% Mo, 0.1 to 0.5% Ni, not more than 0.01% Ca, and not more than 0.1% rare earth metals (REMS) is subjected to induction heating and then water quenching. Here, it is preferable that the cooling rate of said water quenching is 100° C./sec. or higher and the cooling water temperature of said water quenching is 35° C. or lower.

[0013] As explained above, the present invention has been developed with intent to secure a material having more higher TS and a lower YR than a conventional material. A material having such a high TS is generally obtained by subjecting it to water quenching after heating and thus making the structure thereof composed of martensite. In prior technologies, the material property of a low yield ratio has been obtained by making soft austenite and/or ferrite remain partially in a hard martensite structure and thus lowering a proof stress. However, with such prior technologies, as has been explained above, the tensile strength and the yield ratio have been 1,500 to 1,600 MPa and 70 to 80%, respectively, at the least.

[0014] In contrast, in the present invention, while more higher TS than ever is secured by eliminating retained austenite and/or retained ferrite in a martensite structure, YS and YR are lowered by increasing the dislocation density in a hard martensite structure more than ever and thus causing the deformation to occur easily under a stress. A dislocation density in a steel pipe according to the present invention is in the range from 10^{10} to $10^{14}/\text{mm}^{-2}$ and is extremely high whereas a dislocation density in a conventional steel pipe is in the range from 10^8 to $10^9/\text{mm}^{-2}$. By securing such a high dislocation density, a highly impact-resistant steel pipe according to the present invention can have a lower YR than a conventional steel pipe while more higher TS is maintained. Moreover, by employing a 0.1%-proof stress that has not been used as a YS value for calculating a YR value, an impact absorbing capacity can be evaluated more properly and the weight of a door impact beam can be reduced, almost to the limit.

[0015] Further, as explained above, it is thought that the oxides containing Si and Mn, the oxides being formed at an electric-resistance-welded portion, cause the toughness of the welded portion to deteriorate, and the present invention makes it possible to exclude the oxides from an electric-resistance-welded portion and completely prevent the toughness of the welded portion from deteriorating, while a high tensile strength of 1,700 MPa or more is maintained as shown in the data of the after-mentioned examples, by controlling an Si amount in the range from Mn/8–0.07 to Mn/8+0.07.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 is a graph schematically showing the stress-strain curve of a steel.

[0017] FIG. 2 is a graph showing the relationship between cooling rates and YR values.

[0018] FIG. 3 is a graph showing the relationship between cooling water temperatures and YR values.

[0019] FIG. 4 is a graph showing the measurement result of the toughness at upset welded portions.

[0020] FIG. 5 is a graph showing the relationship between the prior austenite grain size numbers and the occurrence of cracks at impact bending tests.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] The present invention is hereunder explained in detail. A highly impact-resistant steel pipe according to the present invention is, as described in claim 11, produced by subjecting a steel pipe containing, in mass, 0.19 to 0.35% C, 0.1 to 0.3% Si, 0.5 to 1.6% Mn, not more than 0.025% P, not more than 0.02% S, 0.010 to 0.050% Al, 2 to 35 ppm B, and 0.005 to 0.05% Ti as indispensable components, and arbitrary components selected from among the group of 0.005 to 0.050% Nb, 0.005 to 0.070% V, 0.005 to 0.5% Cu, 0.005 to 0.5% Cr, 0.1 to 0.5% Mo, 0.1 to 0.5% Ni, not more than 0.01% Ca, and not more than 0.1% rare earth metals (REMs), to induction heating and then water quenching. The reason for regulating the amount of each component is explained below.

[0022] C is a component indispensable for strengthening martensite itself and thus enhancing hardness and must be added by at least 0.19% for securing a TS value of 1,700 MPa or more. However, an excessive C amount makes a martensite structure brittle and baking cracks that cause fracture during quenching occur. Therefore, a C amount is set at not more than 0.35%. Further, it is preferable to set a C amount: at about 0.21% for obtaining a steel pipe having a TS of 1,700 MPa or more and a YR of 72% or less according to the claim 1 of the present invention; at about 0.24% for a steel pipe having a TS of 1,800 MPa or more and a YR of 70% or less according to the claim 2; at about 0.28% for a steel pipe having a TS of 1,900 MPa or more and a YR of 68% or less according to the claim 3; and at about 0.30% for a steel pipe having a TS of 2,000 MPa or more and a YR of 66% or less according to the claim 4.

[0023] Si, Mn and Ti are components for accelerating a transformation from austenite into martensite at the time of quenching. However, when the amounts of Si, Mn and Ti are lower than the amounts specified in the ranges of 0.1 to 0.3% Si, 0.5 to 1.6% Mn and 0.005 to 0.05% Ti, respectively, hardenability deteriorates, retained austenite and/or retained ferrite appear, and thus desired material properties are not obtained. On the other hand, when the amounts of Si, Mn and Ti exceed the above ranges, baking cracks and segregation are undesirably caused. In particular, a preferable Mn amount is 1.0% or more for stabilizing hardenability. Note that Ti has the function of improving hardenability by fixing N.

[0024] B is a component that suppresses the precipitation of ferrite. However, when B combines with N contained in

a steel as a component of a gas and forms BN, the effect is lost. Therefore, a B content is set at 2 ppm or more. On the other hand, when a B content exceeds 35 ppm, B forms segregated inclusions. P and S form segregated inclusions and make a martensite structure brittle. Therefore, the contents of P and S must be 0.025% or less and 0.02% or less, respectively. Al is a deoxidizing agent. However, when an Al amount is less than 0.010%, the deoxidizing effect is insufficient. On the contrary, when an Al amount exceeds 0.050%, the oxides undesirably form intergranular inclusions.

[0025] Nb and V are precipitation hardening components that enhance strength by forming precipitates in a martensite structure and thus preventing dislocations from passing through the precipitates. Cu, Cr, Mo and Ni are solid solution hardening components that enhance strength by dissolving in martensite crystals and thus preventing dislocations from passing through the dissolved components. Note that Cr and Mo function also as precipitation hardening components. Those components, though they contribute to the enhancement of strength, cause the cost to increase and, moreover, form segregated inclusions when they are excessively added. Therefore, their appropriate amounts are 0.005 to 0.050% Nb, 0.005 to 0.07% V, 0.005 to 0.5% Cu, 0.005 to 0.5% Cr, 0.1 to 0.5% Mo and 0.1 to 0.5% Ni.

[0026] Ca and rare earth metals (REMS) are the components that contribute to the control of inclusion shape. However, their excessive addition causes harmful segregation that leads to the destruction of a martensite structure. Therefore, appropriate addition amounts of Ca and rare earth metals (REMS) are 0.01% or less and 0.1% or less, respectively. Note that Nb, V, Cu, Cr, Mo, Ni, Ca and rare earth metals (REMs) are not indispensable components but components selectively added as occasion demands. As the rare earth metals (REMs), for example, Y, La, Ce and Sm may be used.

[0027] In the present invention, a steel having an aforementioned composition is formed into a steel pipe by electric-resistance-welding, thereafter the steel pipe is transferred into a work coil for high frequency heating and heated to a temperature of 900° C. or higher by induction heating, and subsequently the heated steel pipe is quenched with water from the state of austenite. In that case, either of the method wherein the steel pipe passes through a fixed work coil and a fixed water quenching device while the steel pipe is continuously transferred on a conveyor or the method wherein the steel pipe is fixed and a work coil and a water quenching device move along the steel pipe may be employed.

[0028] The transformation from austenite to martensite occurs instantaneously with the water quenching and, at the same time, an expansion of about 7 to 8% is generated due to the transformation strain and the dislocation density in the martensite structure increases drastically. Here, a dislocation density is determined by observing a specimen after subjected to a tensile test according to JIS with a transmission electron microscope, measuring the numbers of dislocations in ten visual fields, the area of each visual field being $1\ \mu\text{m} \times 1\ \mu\text{m}$, and averaging the measured numbers. The unit of a dislocation density is dislocations/ mm^{-2} because the dislocation density is expressed by the dislocation length per unit volume.

[0029] A dislocation density in a steel pipe according to the present invention is in the range from 10^{10} to $10^{14}/\text{mm}^{-2}$ and is extremely high whereas a dislocation density in a conventional steel pipe is in the range from 10^8 to $10^9/\text{mm}^{-2}$. By securing such a high dislocation density, a yield point lowers and therefore a highly impact-resistant steel pipe according to the present invention can have a lower YR than a conventional steel pipe while a higher TS is maintained.

[0030] It is preferable to control a cooling rate at water quenching to 100° C./sec. or higher for obtaining such a highly impact-resistant steel pipe having a high TS and a low YR. **FIG. 2** is a graph showing the relationship between cooling rates and YR values and it is understood from the figure that a YR value decreases abruptly by controlling a cooling rate to 100° C./sec. or higher. This is presumably because a transformation strain occurs abruptly by rapid cooling and a dislocation density increases.

[0031] Further, it is preferable to control a cooling water temperature, at water quenching, to 35° C. or lower for obtaining such a highly impact-resistant steel pipe having a high TS and a low YR. As shown in **FIG. 3**, a YR value increases as a cooling water temperature rises. This is presumably because quenching becomes insufficient as a cooling water temperature rises and an ideal martensite transformation is hard to secure.

[0032] A highly impact-resistant steel pipe according to the present invention produced by aforementioned method can have a lower YR than a conventional steel pipe while a far higher strength is maintained, and therefore, when the steel pipe is used as a member, such as a material for a door impact beam, a bumper, a bumper reinforcement or the like of an automobile, that requires an impact absorption energy, an excellent impact absorbing capacity can be elicited. Further, by employing a 0.1%-proof stress in the present invention instead of a 0.2%-proof stress in prior art, the impact absorbing capacity according to the present invention increases by a degree corresponding to the area hatched with horizontal lines in **FIG. 1** in comparison with the impact absorbing capacity calculated with a 0.2%-proof stress, and therefore the impact absorbing capacity according to the present invention correlates more accurately with an impact absorbing capacity at an actual collision. By so doing, together with a high strength, a weight reduction can be achieved. As a result, it becomes possible to provide a shock absorbing member having both an ultra-low weight and a high collision safety.

[0033] Meanwhile, a highly impact-resistant steel pipe according to the present invention is a steel pipe that secures a high strength of 1,700 MPa or more in tensile strength by inevitably containing 0.10 to 0.30% Si and 0.5 to 1.6% Mn. Thus a transformation from austenite into martensite is accelerated. Further, the most important feature of the present invention is that the toughness of an electric-resistance-welded portion is prevented from deteriorating by controlling the amounts of Si and Mn so as to satisfy the expression $\text{Mn}/8 - 0.07 \leq \text{Si} \leq \text{Mn}/8 + 0.07$. **FIG. 4** is a graph showing the measurement result of the toughness at upset welded portions and it is confirmed from the figure that a relative Charpy absorbed energy is the largest when an Si amount is in the above range.

[0034] Here, a relative Charpy absorbed energy is a relative value defined by the ratio of a Charpy absorbed energy

at -40° C. in the case of $\text{Si}=\text{Mn}/8+\alpha(\alpha=-0.30 \text{ to } +0.30)$ to a Charpy absorbed energy at -40° C. in the case of $\text{Si}=\text{Mn}/8$.

[0035] A steel pipe strengthened up to 1,700 MPa or more by adding C and Mn in the steel as in the present invention has a lower melting point than a steel pipe of a low strength and the viscosity of the oxides formed on the surface of the metal fused at the time of electric-resistance-welding decreases relatively. Therefore, it is particularly important to exclude the oxides by controlling an amount of Si that affects the remaining of the oxides at a welded portion, as mentioned above, to prevent the toughness of the welded portion from deteriorating.

[0036] Further, as shown in the claim 9, it is preferable that 95% or more of the microstructure of a steel pipe is transformed into martensite by induction hardening and the prior austenite grain size number of the steel pipe is #6 or more particularly for securing a low temperature impact bending property. FIG. 5 is a graph showing the result obtained by subjecting highly impact-resistant electric-resistance-welded steel pipes (1,700 MPa in tensile strength) having various prior austenite grain size numbers to impact bending tests and observing the occurrence of cracks. From FIG. 5, it is understood that steel pipes having an excellent low temperature impact bending property are obtained by securing minute crystals having prior austenite grain size numbers of #6 or more. Here, crystals can be fractionized by the effect of, for example, lowering a hardening temperature, fractionizing the grains of a pre-hardening structure, adding elements such as Nb, V, Ti, etc., or the like. A prior austenite grain size number may be measured by exposing the boundaries of prior austenite grains in a base material with a generally used austenite grain boundary exposing liquid and thereafter employing a cutting method or an image analysis method.

[0037] Meanwhile, the sectional shape includes both a round shape and a square shape.

[0038] As methods of producing a square steel pipe having a square sectional shape, there are the method wherein a steel pipe is produced in an electric-resistance-welding process and thereafter the steel pipe is formed into a square sectional shape with forming rolls and the method wherein a steel strip is bent continuously and then formed into a square sectional shape at the time of electric-resistance-welding.

[0039] In the latter case, it is possible that, when the thickness of an ultra-high strength material is so designed as to be thin, the upset allowance is hardly secured at the time of welding and the risk of the remaining of oxides increases. However, even in this case, the present invention makes it possible to exclude oxides and stabilize weld quality by controlling an amount of Si that affects the remaining of oxides as mentioned above and therefore to prevent the toughness of a welded portion from deteriorating.

[0040] It has been estimated that, when an impact energy is absorbed by the deformation of a door impact beam, the impact to a corner is larger than that to a side. To cope with that, in the former method, a welded portion is detected before the roll forming and adjusted so that the welded portion may not be located at a corner. In the latter method, as a steel strip is bent and formed into a square shape, the welded portion is never located at a corner. As explained above, a corner is deviated from a welded portion without fail and it is possible to make the most of the high energy absorbing capacity of a base material. Further, by employing a square steel pipe, it is possible to make the section modulus larger than that of a round steel pipe having an identical sectional area. Therefore, the present invention, by employing a square steel pipe having a square sectional shape, it is possible to enhance an energy absorbing capacity, more than in a round steel pipe, and to increase reliability.

[0041] The examples according to the present invention are explained hereunder.

EXAMPLE 1

[0042] Electric-resistance-welded steel pipes comprising the steels having various compositions shown in Table 1 were produced, heated with induction heating by moving at a constant speed on a conveyor and passing through wire coils, and then rapidly cooled to an ordinary temperature with an adjacent water quenching device. The cooling rates and cooling water temperatures are shown Table 2. The 0.1%-proof stresses and rupture strengths were measured by subjecting cut-out test pieces to a tensile tester. Further, the test pieces after being subjected to the tensile tests were observed with a transmission electron microscope. The resulting dislocation densities are also shown in Table 2.

TABLE 1

	Inventive example 1	Inventive example 2	Inventive example 3	Inventive example 4	Inventive example 5	Inventive example 6	Inventive example 7	Inventive example 8
C (%)	0.21	0.24	0.28	0.28	0.30	0.30	0.35	0.30
Si (%)	0.22	0.23	0.21	0.21	0.20	0.20	0.21	0.20
Mn (%)	1.41	1.43	1.41	1.41	1.44	1.44	1.40	1.00
P (%)	0.021	0.021	0.018	0.018	0.016	0.016	0.020	0.018
S (%)	0.005	0.003	0.003	0.003	0.003	0.003	0.004	0.003
Al (%)	0.025	0.030	0.025	0.025	0.026	0.026	0.023	0.025
B (ppm)	13	11	10	10	10	10	11	10
Ti (%)	0.028	0.030	0.027	0.027	0.027	0.027	0.026	0.025
Nb (%)	—	0.032	0.032	0.032	—	—	—	0.030
V (%)	0.033	0.030	0.035	0.035	—	—	—	—
Ni (%)	—	—	—	—	—	—	0.3	—
Cr (%)	—	—	—	—	0.15	0.15	0.15	—
Cu (%)	0.10	—	—	—	—	—	—	—
REM (%)	—	—	—	0.004	—	—	—	—
Ca (%)	—	—	—	—	—	0.0027	0.0028	—

[0043]

TABLE 2

	Inventive example 1	Inventive example 2	Inventive example 3	Inventive example 4	Inventive example 5	Inventive example 6	Inventive example 7	Inventive example 8
Heating tempera- ture (° C.)	900	900	900	900	900	900	900	900
Cooling rate (° C./sec.)	150	200	200	170	200	200	200	200
Cooling water tempera- ture (° C.)	30	30	30	30	30	30	30	30
Dis- location density (mm ⁻²)	10 ¹²	10 ¹³	10 ¹³	10 ¹³	10 ¹³	10 ¹⁴	10 ¹⁴	10 ¹⁴
0.1%- proof stress (MPa)	1187	1209	1255	1247	1312	1303	1340	1290
Tensile strength (MPa)	1722	1861	1930	1908	2050	2083	2125	2030
Yield ratio (%)	69	65	65	65	64	63	63	64

[0044] As explained above, a highly impact-resistant steel pipe according to the present invention not only has the material properties of a higher strength and a lower yield ratio than a conventional steel pipe but also reflects more precisely an actual impact absorbing capacity by employing a 0.1%-proof stress, and, as a result, agrees better with a member, such as a material for a door impact beam, a bumper, a bumper reinforcement or the like of an automobile, that requires an impact absorption energy. Further, a method according to the present invention makes it possible to produce such a highly impact-resistant steel pipe stably.

EXAMPLE 2

[0045] Electric-resistance-welded steel pipes having various compositions shown in Table 3 were produced and the tensile strength, the ratio of the strength of a welded portion to that of a body portion, the occurrence of cracks at low temperature impact bending, and others of each of the steel pipes were measured. The results are shown in Table 3. The value of $\alpha = \text{Si-Mn}/8$ and the prior austenite grain size number of each of the steel pipes are also shown in Table 3. The invention examples 9 to 13 and the comparative examples 1 to 3 are the examples of round-shaped electric-resistance-welded steel pipes and the invention examples 14 and 15 and the comparative example 4 are the examples of square-shaped electric-resistance-welded steel pipes having quadratic sectional shapes.

TABLE 3

	Inventive example 9	Inventive example 10	Inventive example 11	Inventive example 12	Inventive example 13	Inventive example 14	Inventive example 15	Compara- tive example 1	Compara- tive example 2	Compara- tive example 3	Compara- tive example 4
C	0.24	0.28	0.28	0.30	0.33	0.28	0.30	0.30	0.30	0.30	0.30
Si	0.15	0.24	0.13	0.20	0.20	0.14	0.15	0.10	0.30	0.30	0.35
Mn	1.41	1.43	1.25	1.43	1.44	1.30	1.35	1.50	1.00	1.00	1.00
P	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
S	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.005	0.005	0.005	0.005
Al	0.028	0.023	0.026	0.022	0.029	0.025	0.025	0.024	0.022	0.022	0.026
B	13	12	10	14	11	12	14	10	13	13	13
Ti	0.025	0.026	0.024	0.024	0.025	0.024	0.025	0.026	0.026	0.026	0.027
Nb		0.03						0.03			
V	0.03						0.03				
Ni			0.03								
Cr				0.15	0.13		0.15				
Cu											
REM											
Ca					0.03						
α	-0.03	+0.06	-0.03	+0.02	+0.02	-0.02	-0.02	-0.09	+0.18	+0.18	+0.23

TABLE 3-continued

	Inventive example 9	Inventive example 10	Inventive example 11	Inventive example 12	Inventive example 13	Inventive example 14	Inventive example 15	Compara- tive example 1	Compara- tive example 2	Compara- tive example 3	Compara- tive example 4
Grain size number	7	6	7	7	7	7	7	7	7	5	7
Strength	1861	1908	1911	1995	2125	1925	2015	2005	1992	1907	1985
Welded portion strength ratio	1.2	1.3	1.8	1.4	1.3	1.2	1.3	0.5	0.4	0.4	0.4
Low tempera- ture impact bending	○	○	○	○	○	○	○	○	○	x	x

[0046] Here, the amount of each component in Table 3 is expressed in terms of mass % (except B which is expressed in terms of mass ppm) and the balance of the components consists of Fe and unavoidable impurities. In the column of "Low temperature impulse bending," the mark ○ represents the case where no cracks occur when a steel pipe is subjected to an impact bending test under the condition of a low temperature of -60°C . and the mark X the case where cracks occur. The strength means a tensile strength and the unit thereof is MPa. When the box of a component is blank, it means the component is not added.

[0047] Further, though it is not shown in Table 3, the maximum values of the absorbed impact energy of the invention examples 14 and 15 are somewhat larger than those of the invention examples 9 to 13. This is presumably because the section moduli of the invention examples 14 and 15 are larger.

[0048] As explained above, a highly impact-resistant electric-resistance-welded steel pipe having a round or square sectional shape according to the present invention not only is excellent in strength and toughness but also does not undergo deterioration of strength and toughness in the vicinity of an electric-resistance-welded portion and is suitable for using as an impact absorbing member such as a material for a door impact beam bumper, or a bumper reinforcement, or the like.

1. A highly impact-resistant steel pipe characterized in that: the tensile strength TS of said steel pipe is 1,700 MPa or more; and the YR thereof, said YR being the ratio of the 0.1%-proof stress YS to said tensile strength TS (YS/TS), is 72% or less.

2. A highly impact-resistant steel pipe characterized in that: the tensile strength TS of said steel pipe is 1,800 MPa or more; and the YR thereof, said YR being the ratio of the 0.1%-proof stress YS to said tensile strength TS (YS/TS), is 70% or less.

3. A highly impact-resistant steel pipe characterized in that: the tensile strength TS of said steel pipe is 1,900 MPa or more; and the YR thereof, said YR being the ratio of the 0.1%-proof stress YS to said tensile strength TS (YS/TS), is 68% or less.

4. A highly impact-resistant steel pipe characterized in that: the tensile strength TS of said steel pipe is 2,000 MPa

or more; and the YR thereof, said YR being the ratio of the 0.1%-proof stress YS to said tensile strength TS (YS/TS), is 66% or less.

5. A highly impact-resistant electric-resistance-welded steel pipe characterized in that: the tensile strength TS of said steel pipe is 1,700 MPa or more; and the Si amount in the steel of said steel pipe is controlled in the range from Mn/8-0.07 to Mn/8+0.07 (mass %).

6. A highly impact-resistant steel pipe according to any one of claims 1 to 4, characterized in that the dislocation density of said steel pipe is in the range from 10^{10} to $10^{14}/\text{mm}^{-2}$.

7. A highly impact-resistant steel pipe according to any one of claims 1 to 5, characterized in that the steel of said steel pipe contains, in mass, 0.19 to 0.35% C, 0.10 to 0.30% Si, 0.5 to 1.60% Mn, not more than 0.025% P, not more than 0.01% S, 0.010 to 0.050% Al, 2 to 35 ppm B, and 0.005 to 0.05% Ti as indispensable components.

8. A highly impact-resistant steel pipe according to claim 7, characterized in that the steel of said steel pipe further contains, in mass, one or more components selected from among the group of 0.005 to 0.050% Nb, 0.005 to 0.070% V, 0.005 to 0.5% Cu, 0.1 to 0.5% Mo, 0.1 to 0.5% Ni, not more than 0.01% Ca, and not more than 0.1% rare earth metals (REMs).

9. A highly impact-resistant steel pipe according to any one of claims 1 to 5, characterized in that 95% or more of the microstructure of said steel pipe is transformed into martensite by induction hardening and the prior austenite grain size number of said steel pipe is #6 or more.

10. A highly impact-resistant steel pipe according to any one of claims 1 to 5, characterized in that said steel pipe has a round or square sectional shape.

11. A method for producing a highly impact-resistant steel pipe according to any one of claims 1 to 5, characterized in that said steel pipe containing, in mass, 0.19 to 0.35% C, 0.10 to 0.30% Si, 0.5 to 1.60% Mn, not more than 0.025% P, not more than 0.01% S, 0.010 to 0.050% Al, 2 to 35 ppm B, and 0.005 to 0.05% Ti as indispensable components, and further one or more components selected from among the group of 0.005 to 0.050% Nb, 0.005 to 0.070% V, 0.005 to 0.5% Cu, 0.1 to 0.5% Mo, 0.1 to 0.5% Ni, not more than

0.01% Ca, and not more than 0.1% rare earth metals (REMs), is subjected to induction heating and then water quenching.

12. A method for producing a highly impact-resistant steel pipe according to claim 11, characterized in that the cooling rate of said water quenching is 100° C./sec. or higher.

13. A method for producing a highly impact-resistant steel pipe according to claim 11 or **12**, characterized in that the cooling water temperature of said water quenching is 35° C. or lower.

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