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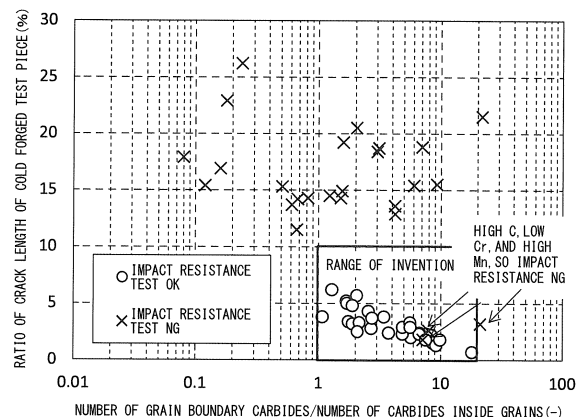
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(54) **STEEL SHEET AND METHOD FOR PRODUCING SAME**

(57) Low carbon steel plate excellent impact resistance characteristics after carburizing and quenching and after tempering, characterized by having a predetermined chemical composition, an average grain size of carbides of 0.4  $\mu\text{m}$  to 2.0  $\mu\text{m}$ , an area ratio of pearlite of 6% or less, a ratio of a number of carbides at the ferrite grain boundaries to the number of carbides inside the ferrite grains of over 1, and a Vickers hardness of 100HV to 180HV.

FIG. 3



**Description**

## Technical Field

5 **[0001]** The present invention relates to steel plate and a method of production of the same.

## Background Art

10 **[0002]** Steel plate containing, by mass%, carbon in an amount of 0.1 to 0.4% is being used as a material for gears, clutches, and other drive system parts of automobiles by being used press-formed, enlarging holes, bent, drawn, thickened, and thinned and cold forged by combinations of the same from a blank. Compared with conventional hot forging etc., with cold forging, there is the problem that the amount of strain accumulated in the material becomes higher, cracks of the material and buckling at the time of shaping are invited, and deterioration of the part characteristics is caused.

15 **[0003]** In particular, to obtain wear resistance, after the shaped material is carburized, quenched, and tempered, residual stress is caused by the heat treatment, so formation and growth of fracture from the cracked parts and buckled parts are invited. To use such a part for the drive system, an impact resistance characteristic is sought for preventing fracture due to brittleness in the face of the large instantaneous load applied to the start of engagement of the gears at the time of startup etc., so excellent cold forgeability and impact resistance characteristic after carburizing, quenching, and tempering are being demanded from the above steel plate.

20 **[0004]** Up to now, various proposals have been made regarding arts for improving the cold forgeability of steel plate and the impact resistance characteristic after carburization (for example, see PLTs 1 to 5).

25 **[0005]** For example, PLT 1 discloses, as steel for machine structural use improving toughness by suppressing coarsening of crystal grains in carburization heat treatment, steel for machine structural use containing, by mass%, C: 0.10 to 0.30%, Si: 0.05 to 2.0%, Mn: 0.10 to 0.50%, P: 0.030% or less, S: 0.030% or less, Cr: 1.80 to 3.00%, Al: 0.005 to 0.050%, Nb: 0.02 to 0.10%, and N: 0.0300% or less and having a balance of Fe and unavoidable impurities, having a structure before cold working comprised of ferrite and pearlite structures, and having an average grain size of ferrite grains of 15  $\mu\text{m}$  or more.

30 **[0006]** PLT 2 discloses, as steel excellent in cold workability and carburizing and quenching ability, steel containing C: 0.15 to 0.40%, Si: 1.00% or less, Mn: 0.40% or less, sol. Al: 0.02% or less, N: 0.006% or less, and B: 0.005 to 0.050%, having a balance of Fe and unavoidable impurities, and having a structure mainly comprised of ferrite phases and graphite phases.

**[0007]** PLT 3 discloses a steel material for carburized bevel gear use excellent in impact strength, a high toughness carburized bevel gear, and a method of production of the same.

35 **[0008]** PLT 4 discloses steel for carburized part use having excellent workability while suppressing coarsening of crystal grains even with subsequent carburization and having an excellent impact resistance characteristic and impact fatigue resistance characteristic in a part produced by spheroidal annealing, then a cold forging and a carburizing, quenching, and tempering process.

40 **[0009]** PLT 5 discloses as cold tool steel for plasma carburization use a steel containing C: 0.40 to 0.80%, Si: 0.05 to 1.50%, Mn: 0.05 to 1.50%, and V: 1.8 to 6.0%, further containing one or more of Ni: 0.10 to 2.50%, Cr: 0.1 to 2.0%, and Mo: 3.0% or less, and having a balance of Fe and unavoidable impurities.

## Citation List

## Patent Literature

45 **[0010]** PLT 1: Japanese Patent Publication No. 2013-040376A

PLT 2: Japanese Patent Publication No. 06-116679A

PLT 3: Japanese Patent Publication No. 09-201644A

50 PLT 4: Japanese Patent Publication No. 2006-213951A

PLT 5: Japanese Patent Publication No. 10-158780A

## Summary of Invention

## 55 Technical Problem

**[0011]** The structure of the steel for machine structural use of PLT 1 is a structure of ferrite + pearlite. This structure, compared with a ferrite + cementite structure, has a large hardness, so wear of the die in cold forging cannot be

suppressed and the steel cannot necessarily be said to be steel for machine structural use excellent in cold forgeability.

**[0012]** In the steel of PLT 2, the graphitization treatment of the cementite requires annealing at a high temperature. A drop in the yield and an increase in the manufacturing costs cannot be suppressed.

**[0013]** The method of production of PLT 3 requires further hot forging after cold forging and carburizing. Since hot forging is essential, this is not a method of production leading to fundamentally lower costs.

**[0014]** It is unclear if the steel for carburized part use of PLT 4 can exhibit similar effects in cold forging given a large strain. Furthermore, the specific form of the structure and method of control of the structure are also unclear, so this cannot be said to be steel exhibiting excellent workability even in the plate forging growing in use in recent years and other shaping by forging cold while giving a large strain.

**[0015]** PLT 5 does not disclose at all the findings and art relating to the optimum components and form of structure for improving the formability of steel, in particular cold forgeability.

**[0016]** The present invention, in consideration of the above prior art, has as its problem the provision of steel plate excellent in cold forgeability and impact resistance characteristic after carburizing, quenching, and tempering, in particular suitable for obtaining a high cycle gear or other part by forming a plate and of a method of production of the same.

#### Solution to Problem

**[0017]** To solve the above problem and obtain steel plate suitable for a material such as a drive system part, it is understood that in a steel plate containing the C required for raising the hardenability, enlargement of the ferrite in grain size, spheroidization of the carbides (mainly cementite) to a suitable grain size, and reduction of the pearlite structures are preferable. This is due to the following reasons.

**[0018]** A ferrite phase is low in hardness and high in ductility. Therefore, in a structure mainly comprised of ferrite, it becomes possible to increase the grain size so as to raise the formability of the material.

**[0019]** Carbides, by being made to suitably disperse in the metal structure, can maintain the formability of the material while imparting an excellent wear resistance and rolling fatigue characteristic, so provides a structure essential for drive system parts. Further, the carbides in the steel plate are strong particles obstructing slip. By forming carbides at the ferrite grain boundaries, it is possible to prevent propagation of slip exceeding the crystal grain boundaries and suppress the formation of shear zones. Thus the cold forgeability is improved and, simultaneously, the formability of steel plate is also improved.

**[0020]** However, cementite is a hard, brittle structure. If a laminar structure with ferrite present, that is, in the state of pearlite, the steel becomes hard and brittle, so it has to be present in a spheroidal form. If considering the cold forgeability and the occurrence of fractures at the time of forging, its grain size has to be a suitable range.

**[0021]** However, no method of production for realizing the above structure has been disclosed up to now. Therefore, the inventors intensively researched a method of production for realizing the above structure.

**[0022]** As a result, they discovered the following: To make the metal structure of the steel plate after coiling after hot rolling a bainite structure of fine pearlite or fine ferrite with small lamellar spacing in which cementite is dispersed, the steel plate is coiled at a relatively low temperature (400°C to 550°C). By coiling at a relatively low temperature, the cementite dispersed in the ferrite also easily becomes spheroidal. Next, the cementite is partially made spheroidal by annealing at a temperature just under the Ac1 point as first stage annealing. Next, as second stage annealing, part of the ferrite grains is left while part is transformed to austenite by annealing at a temperature between the Ac1 point and Ac3 point (so-called dual phase region of ferrite and austenite). By then making the remaining ferrite grains grow while slowly cooling the steel while using these as nuclei to transform the austenite to ferrite, it is possible to obtain large ferrite phases and make cementite precipitate at the grain boundaries to realize the above structure.

**[0023]** That is, the method of production of steel plate simultaneously satisfying hardenability and formability is difficult to realize even if designing the hot rolling conditions, annealing conditions, etc. as single processes. It was discovered that this can be realized by optimization by a so-called integral process of hot rolling, an annealing process, etc.

**[0024]** Further, improvement of the drawability at the time of cold forging requires the reduction of plastic anisotropy. It was discovered that for such improvement, adjustment of the hot rolling conditions is important.

**[0025]** The present invention was made based on these discoveries and has as its gist the following:

**[0026]** (1) A steel plate being low carbon steel plate having a chemical composition containing, by mass%, C: 0.10 to 0.40%, Si: 0.01 to 0.30%, Mn: 0.30 to 1.00%, Al: 0.001 to 0.10%, Cr: 0.50 to 2.00%, Mo: 0.001 to 1.00%, P: 0.020% or less, S: 0.010% or less, N: 0.020% or less, O: 0.020% or less, Ti: 0.010% or less, B: 0.0005% or less, Sn: 0.050% or less, Sb: 0.050% or less, As: 0.050% or less, Nb: 0.10% or less, V: 0.10% or less, Cu: 0.10% or less, W: 0.10% or less, Ta: 0.10% or less, Ni: 0.10% or less, Mg: 0.050% or less, Ca: 0.050% or less, Y: 0.050% or less, Zr: 0.050% or less, La: 0.050% or less, and Ce: 0.050% and having a balance of Fe and impurities, the metal structure of the steel plate having a carbide grain size of 0.4 to 2.0  $\mu\text{m}$ , a pearlite area ratio of 6% or less, and a ratio of a number of carbides at the ferrite grain boundaries to the number of carbides inside the ferrite grains of over 1, the steel plate having a Vickers hardness of 100HV to 180HV.

**[0027]** (2) A method of production of the steel plate according to (1), the method of production comprising the steps of: hot rolling a steel slab of a chemical composition according to claim 1, completing finish hot rolling in a 650°C to 950°C temperature region to obtain a hot rolled steel plate; coiling the hot rolled steel plate at 400°C to 600°C; pickling the coiled hot rolled steel plate and heating the pickled hot rolled steel plate by a 30°C/hour to 150°C/hour heating rate to a 650°C to 720°C annealing temperature and holding it there for 3 hours to 60 hours as first stage annealing; then heating the hot rolled steel plate to an annealing temperature of 725°C to 790°C by a heating rate of 1°C/hour to 80°C/hour and holding the steel plate for 3 hours to 50 hours as second stage annealing; and cooling the annealed hot rolled steel plate to 650°C by a cooling rate of 1°C/hour to 100°C/hour.

**[0028]** According to the present invention, it is possible to provide a steel plate excellent in cold forgeability and impact resistance characteristic after carburizing, quenching, and tempering, in particular one suitable for obtaining a high cycle gear or other part by forming a plate.

#### Brief Description of Drawings

#### **[0029]**

FIGS. 1A to 1C are views schematically showing a summary of the cold forging test and the form of a crack introduced by cold forging. FIG. 1A shows a disk-shaped test material cut out from a hot rolled steel plate, while FIG. 1B shows the shape of a test material after cold forging, while FIG. 1C shows the cross-sectional shape of the test material after cold forging.

FIG. 2 is a view schematically showing a summary of a drop weight test evaluating the impact resistance characteristic of a sample performing carburizing, quenching, and tempering.

FIG. 3 is a view showing a relationship among a ratio of a number of carbides at the grain boundaries to the number of carbides in the grains, the crack length of the cold forging test piece, and the impact resistance characteristic after carburizing, quenching, and tempering.

FIG. 4 is a view showing another relationship among a ratio of a number of carbides at the grain boundaries to the number of carbides in the grains, the crack length of the cold forging test piece, and the impact resistance characteristic after carburizing, quenching, and tempering.

#### Description of Embodiments

**[0030]** Below, the present invention will be explained in detail. First, the reasons for limitation of the chemical composition of the steel plate of the present invention will be explained. Here, the "%" according to the chemical composition means "mass%".

C: 0.10 to 0.40%

**[0031]** C is an element forming carbides in steel and effective for strengthening the steel and refining the ferrite grains. To suppress the formation of a matte surface in cold working and secure surface beauty of a cold forged part, suppression of coarsening of the ferrite grain size is essential, but if less than 0.10%, the carbides become insufficient in volume fraction and coarsening of the carbides during annealing can no longer be suppressed, so C is made 0.10% or more. Preferably it is 0.11% or more.

**[0032]** On the other hand, if exceeding 0.40%, the carbides increase in volume fraction, a large amount of cracks are formed acting as starting points of breakage at the time of an instantaneous load and a drop in the impact resistance characteristic is invited, so C is made 0.40% or less. Preferably it is 0.38% or less.

Si: 0.01 to 0.30%

**[0033]** Si is an element which acts as a deoxidizing agent and further has an effect on the form of the carbides. To reduce the number of carbides in the ferrite grains giving the deoxidizing effect and increase the number of carbides at the ferrite grain boundaries, it is necessary to use two-stage step type annealing to produce austenite phases during annealing, make the carbides dissolve once, then gradually cool the structure to promote the formation of carbides at the ferrite grain boundaries.

**[0034]** If Si exceeds 0.30%, the ferrite falls in ductility, fractures are easily formed at the time of cold forging, and the cold forgeability and impact resistance characteristic after carburizing, quenching, and tempering deteriorate, so Si is made 0.30% or less. Preferably it is 0.28% or less.

**[0035]** Si is preferably as low as possible, but reduction to less than 0.01% invites a large increase in refining costs, so Si is made 0.01% or more. Preferably it is 0.02% or more.

Mn: 0.30 to 1.00%

**[0036]** Mn is an element controlling the form of carbides in two-stage step type annealing. If less than 0.30%, in the gradual cooling after second stage annealing, it becomes difficult to form carbides at the ferrite grain boundaries, so Mn is made 0.30% or more. Preferably it is 0.33% or more.

**[0037]** On the other hand, if exceeding 1.00%, the toughness after carburizing, quenching, and tempering falls, so Mn is made 1.00% or less. Preferably it is 0.96% or less.

Al: 0.001 to 0.10%

**[0038]** Al is an element acting as a deoxidizing agent of steel and stabilizing ferrite. If less than 0.001%, the effect of addition is not sufficiently obtained, so Al is made 0.001% or more. Preferably it is 0.004% or more.

**[0039]** On the other hand, if exceeding 0.10%, the number ratio of carbides at the grain boundaries is lowered and an increase in crack length at the time of cold forging is invited, so Al is made 0.10% or less. Preferably it is 0.09% or less.

Cr: 0.50 to 2.00%

**[0040]** Cr and Mo are elements which improve the toughness. Cr is an element effective for stabilization of carbides at the time of heat treatment. If less than 0.50%, it becomes difficult to cause carbides to remain at the time of carburization, coarsening of the austenite grain size at the surface layer is invited, and a drop in the impact resistance characteristic is caused, so Cr is made 0.50% or more. Preferably it is 0.52% or more.

**[0041]** On the other hand, if exceeding 2.00%, the amount of Cr concentrating at the carbides increases and a large amount of fine carbides remain in the austenite phases produced by the two-stage step type annealing, carbides remain in the grains after gradual cooling, the hardness increases and number ratio of carbides at the grain boundaries fall and the cold forgeability falls, so Cr is made 2.00% or less. Preferably it is 1.94% or less.

Mo: 0.001 to 1.00%

**[0042]** Mo is an element effective for control of the form of carbides. If less than 0.001%, the effect of addition is not sufficiently obtained, so Mo is made 0.001% or more. Preferably it is 0.017% or more.

**[0043]** On the other hand, if exceeding 1.00%, Mo concentrates in the carbides and stable carbides increase in the austenite phase as well, so after gradual cooling, carbides are present in the grains as well, an increase in hardness and drop in number ratio of carbides at the grain boundaries are invited, and the cold forgeability falls, so Mo is made 1.00% or less. Preferably it is 0.94% or less.

**[0044]** The following elements are impurities and have to be controlled to certain amounts or less.

P: 0.020% or less

**[0045]** P is an element segregating at the ferrite grain boundaries and suppressing the formation of carbides at the grain boundaries. The smaller amount is preferable. The content of P may also be 0, but a long time is required for refining in order to make the purity a high one of less than 0.0001% in a refining process and a large increase in the manufacturing cost is invited, so the de facto lower limit is 0.0001 to 0.0013%.

**[0046]** On the other hand, if exceeding 0.020%, the number ratio of carbides at the grain boundaries falls and the cold forgeability falls, so P is made 0.020% or less. Preferably it is 0.018% or less.

S: 0.010% or less

**[0047]** S is an impurity element forming MnS and other nonmetallic inclusions. The nonmetallic inclusions form starting points of formation of fractures at the time of cold forging, so the smaller the S, the better. The content of S may also be 0, but to lower S to less than 0.0001%, the refining costs greatly increase, so the de facto lower limit is 0.0001 to 0.0012%.

**[0048]** On the other hand, if exceeding 0.010%, an increase is invited in the crack length at the time of cold forging, so S is made 0.010% or less. Preferably it is 0.009% or less.

N: 0.020% or less

**[0049]** N is an element segregating at the ferrite grain boundaries and suppressing the formation of carbides at the grain boundaries. The smaller amount is preferable. The content of N may also be 0, but if reducing it to less than

0.0001%, the refining costs greatly increase, so the de facto lower limit is 0.0001 to 0.0006%.

**[0050]** On the other hand, if exceeding 0.020%, even if performing dual phase region annealing and gradual cooling, the ratio of the number of carbides at the ferrite grain boundaries with respect to the number of carbides in the ferrite grains becomes less than 1 and the cold forgeability falls, so N is made 0.020% or less. Preferably it is 0.017% or less.

O: 0.0001 to 0.020%

**[0051]** O is an element forming oxides in the steel. The oxides present in the ferrite grains become sites for production of carbides, so the smaller the amount, the better. The content of O may also be 0, but if reducing O to less than 0.0001%, the refining costs greatly increase, so the de facto lower limit is 0.0001 to 0.0006%.

**[0052]** On the other hand, if exceeding 0.020%, the ratio of the number of carbides at the ferrite grain boundaries with respect to the number of carbides in the ferrite grains becomes less than 1 and the cold forgeability falls, so O is made 0.020% or less. Preferably it is 0.017% or less.

Ti: 0.010% or less

**[0053]** Ti is an element important for control of the form of the carbides. It is an element by which, by inclusion in a large amount, formation of carbides in the ferrite grains is promoted. The smaller amount is preferable. The content of Ti may also be 0, but if reducing it to less than 0.0001%, the refining costs greatly increase, so the de facto lower limit is 0.0001 to 0.0006%.

**[0054]** On the other hand, if over 0.010%, the ratio of the number of carbides at the ferrite grain boundaries to the number of carbides inside the ferrite grains becomes less than 1 and the cold forgeability falls, so Ti is made 0.010% or less. Preferably it is 0.007% or less.

B: 0.0005% or less

**[0055]** B is an element effective for control of slip of dislocations at the time of cold forging. By inclusion of a large amount, activity of the slip system is limited, so the smaller the amount of B, the better. The content of B may also be 0. Fine care is required for detection of less than 0.0001% of B. Depending on the analysis device, it is below the lower limit of detection.

**[0056]** On the other hand, if exceeding 0.0005%, cross slip of dislocations at the shear zone formed by the cold forging is suppressed. Strain concentrates locally and fractures are formed, so B is made 0.0005% or less. Preferably it is 0.0005% or less.

Sn: 0.050% or less

**[0057]** Sn is an element entering from the steel starting materials (scraps). The smaller amount is preferable. The content of Sn may also be 0, but if reducing it to less than 0.001%, the refining costs greatly increase, so the de facto lower limit is 0.001 to 0.002%.

**[0058]** On the other hand, if exceeding 0.050%, the ferrite becomes brittle and the cold forgeability falls, so Sn is made 0.050% or less. Preferably, it is 0.048% or less.

Sb: 0.050% or less

**[0059]** Sb, like Sn, is an element entering from the steel starting materials (scraps). Sb segregates at the grain boundaries and lowers the number ratio of carbides at the grain boundaries, so the smaller the amount, the better. The content of Sb may also be 0, but if reducing it to less than 0.001%, the refining costs greatly increase, so the de facto lower limit is 0.001 to 0.002%.

**[0060]** On the other hand, if exceeding 0.050%, the cold forgeability falls, so Sb is made 0.050% or less. Preferably, it is 0.048% or less.

As: 0.050% or less

**[0061]** As is an element which enters from the steel starting materials (scraps) like Sn and Sb. As segregates at the grain boundaries and lowers the number ratio of carbides at the grain boundaries, so the content is preferably small. The content of As may also be 0, but if reducing it to less than 0.001%, the refining cost greatly increases, so the de facto lower limit is 0.001 to 0.002%.

**[0062]** On the other hand, if over 0.050%, the number ratio of carbides at the grain boundaries falls and the cold

forgeability falls, so As is made 0.050% or less. Preferably it is 0.045% or less.

**[0063]** The steel plate of the present invention has the above elements as basic elements, but may further contain the following elements for the purpose of improving the cold forgeability and other characteristics. The following elements are not essential for obtaining the effects of the present invention, so the contents may also be 0.

Nb: 0.10% or less

**[0064]** Nb is an element effective for control of the form of the carbides. Further, it is an element refining the structure and contributing to improvement of the toughness. If less than 0.001%, the effect of addition is not sufficiently obtained, so Nb is preferably made 0.001% or more. More preferably, it is 0.002% or more.

**[0065]** On the other hand, if over 0.10%, a large number of fine Nb carbides precipitate, the strength excessively rises, and, further, the number ratio of carbides at the grain boundaries falls and the cold forgeability falls, so Nb is made 0.10% or less. Preferably it is 0.09% or less.

V: 0.10% or less

**[0066]** V, like Nb, is an element effective for control of the form of the carbides. Further, it is an element refining the structure and contributing to improvement of the toughness. If less than 0.001%, the effect of addition is not sufficiently obtained, so V is preferably made 0.001% or more. More preferably, it is 0.004% or more.

**[0067]** On the other hand, if over 0.10%, a large number of fine V carbides precipitate, the strength excessively rises, and, further, the number ratio of carbides at the grain boundaries falls and the cold forgeability falls, so V is made 0.10% or less. Preferably, it is 0.09% or less.

Cu: 0.10% or less

**[0068]** Cu is an element forming fine precipitates and contributing to improvement of the strength. If less than 0.001%, the effect of improvement of the strength is not sufficiently obtained, so Cu is preferably made 0.001% or more. More preferably, it is 0.008% or more.

**[0069]** On the other hand, if over 0.10%, red hot embrittlement occurs during hot rolling and the productivity falls, so Cu is made 0.10% or less. Preferably, it is 0.09% or less.

W: 0.10% or less

**[0070]** W, like Nb and V, is an element effective for control of the form of the carbides. If less than 0.001%, the effect of addition is not sufficiently obtained, so W is preferably made 0.001% or more. More preferably, it is 0.003% or more.

**[0071]** On the other hand, if over 0.10%, a large number of fine W carbides precipitate, the strength excessively rises, and, further, the number ratio of carbides at the grain boundaries falls and the cold forgeability falls, so W is made 0.10% or less. Preferably, it is 0.08% or less.

Ta: 0.10% or less

**[0072]** Ta, like Nb, V, and W, is an element effective for control of the form of the carbides. If less than 0.001%, the effect of addition is not sufficiently obtained, so Ta is preferably made 0.001% or more. More preferably, it is 0.007% or more.

**[0073]** On the other hand, if over 0.10%, a large number of fine Ta carbides precipitate, the strength excessively rises, and, further, the number ratio of carbides at the grain boundaries falls and the cold forgeability falls, so Ta is made 0.10% or less. Preferably, it is 0.09% or less.

Ni: 0.10% or less

**[0074]** Ni is an element effective for improvement of the impact resistance characteristic of parts. If less than 0.001%, the effect of addition is not sufficiently obtained, so Ni preferably is made 0.001% or more. More preferably it is 0.002% or more.

**[0075]** On the other hand, if over 0.10%, the number ratio of carbides at the grain boundaries falls and the cold forgeability falls, so Ni is made 0.10% or less. Preferably, it is 0.09% or less.

Mg: 0.050% or less

**[0076]** Mg is an element which can control the form of sulfides by addition in a trace amount. If less than 0.0001%, the effect of addition is not sufficiently obtained, so Mg preferably is made 0.0001% or more. More preferably it is 0.0008% or more.

**[0077]** On the other hand, if over 0.050%, the ferrite becomes brittle and the cold forgeability falls, so Mg is made 0.050% or less. Preferably it is 0.049% or less.

Ca: 0.050% or less

**[0078]** Ca, like Mg, is an element which can control the form of sulfides by addition in a trace amount. If less than 0.001%, the effect of addition is not sufficiently obtained, so Ca preferably is made 0.001% or more. More preferably it is 0.003% or more.

**[0079]** On the other hand, if over 0.050%, coarse Ca oxides are formed and become starting points of fracture at the time of cold forging, so Ca is made 0.050% or less. Preferably it is 0.04% or less.

Y: 0.050% or less

**[0080]** Y, like Mg and Ca, is an element which can control the form of sulfides by addition in a trace amount. If less than 0.001%, the effect of addition is not sufficiently obtained, so Y preferably is made 0.001% or more. More preferably it is 0.003% or more.

**[0081]** On the other hand, if over 0.050%, coarse Y oxides are formed and become starting points of fracture at the time of cold forging, so Y is made 0.050% or less. Preferably it is 0.031% or less.

Zr: 0.050% or less

**[0082]** Zr, like Mg, Ca, and Y, is an element which can control the form of sulfides by addition in a trace amount. If less than 0.001%, the effect of addition is not sufficiently obtained, so Zr preferably is made 0.001% or more. More preferably it is 0.004% or more.

**[0083]** On the other hand, if over 0.050%, coarse Zr oxides are formed and become starting points of fracture at the time of cold forging, so Zr is made 0.050% or less. Preferably it is 0.045% or less.

La: 0.050% or less

**[0084]** La is an element effective for control of the form of sulfides by addition in a trace amount. Further, it is an element which segregates at the grain boundaries and lowers the number ratio of carbides at the grain boundaries. If less than 0.001%, the effect of control of the form is not sufficiently obtained, so La is preferably made 0.001% or more. More preferably, it is 0.003% or more.

**[0085]** On the other hand, if over 0.050%, the number ratio of carbides at the grain boundaries falls and the cold forgeability falls, so La is made 0.050% or less. Preferably it is 0.047% or less.

Ce: 0.050% or less

**[0086]** Ce, like La, is an element able to control the form of sulfides by addition in a trace amount. Further, it is an element which segregates at the grain boundaries and lowers the number ratio of carbides at the grain boundaries. If less than 0.001%, the effect of control of the form is not sufficiently obtained, so Ce is preferably made 0.001% or more. More preferably, it is 0.003% or more.

**[0087]** On the other hand, if exceeding 0.050%, the number ratio of carbides at the grain boundaries falls and the cold forgeability falls, so Ce is made 0.050% or less. Preferably it is 0.046% or less.

**[0088]** Note that, the remainder of the chemical composition of the steel plate of the present invention is comprised of Fe and unavoidable impurities.

**[0089]** Next, the structure of the steel plate of the present invention will be explained.

**[0090]** The structure of the steel plate of the present invention is substantially a structure comprised of ferrites and carbides. The carbides include cementite ( $\text{Fe}_3\text{C}$ ) which is a compound of iron and carbon, a compound obtained by substituting Mn, Cr, etc. for the Fe atoms in the cementite, and alloy carbides ( $\text{M}_{23}\text{C}_6$ ,  $\text{M}_6\text{C}$ , MC, etc., where M is Fe and other metal elements).

**[0091]** When forming steel plate into a predetermined part shape, a shear zone is formed at the macrostructure of the steel plate and slip deformation occurs concentrated near the shear zone. In slip deformation, along with proliferation

of dislocations, a region of a high dislocation density is formed near the shear zone. Along with the increase in the amount of strain imparted to the steel plate, slip deformation is promoted and the dislocation density increases.

**[0092]** In cold forging, strong working is performed with an equivalent strain exceeding 1. For this reason, in conventional steel plate, it was not possible to prevent the formation of voids and/or cracks along with the increase in dislocation density and was difficult to improve the cold forgeability.

**[0093]** To solve this difficult problem, it is effective to suppress the formation of a shear zone at the time of forming. From the viewpoint of the microstructure, formation of a shear zone can be understood as the phenomenon of slip occurring at a certain one grain crossing the crystal grain boundary and being continuously propagated to the adjoining grain. Accordingly, to suppress the formation of a shear zone, it is necessary to prevent propagation of slip crossing crystal grain boundaries.

**[0094]** The carbides in steel plate are strong particles inhibiting slip. By forming carbides at the ferrite grain boundaries, it becomes possible to suppress the formation of a shear zone and improve the cold forgeability.

**[0095]** To obtain such an effect, carbides have to be made to disperse in the metal structure in suitable sizes. Therefore, the average particle size of carbides is made 0.4  $\mu\text{m}$  to 2.0  $\mu\text{m}$ . If the particle size of the carbides is less than 0.4  $\mu\text{m}$ , the steel plate remarkably increases in hardness and the cold forgeability falls. More preferably it is 0.6  $\mu\text{m}$  or more.

**[0096]** On the other hand, if the average particle size of the carbides exceeds 2.0  $\mu\text{m}$ , at the time of cold forming, the carbides form starting points of fractures. More preferably, it is 1.95  $\mu\text{m}$  or less.

**[0097]** Further, cementite, a carbide of iron, has a hard and brittle structure. If present in the form of pearlite, which is a layered structure with ferrite, the steel becomes hard and brittle. Therefore, pearlite has to be reduced as much as possible. In the steel plate of the present invention, the area ratio is made 6% or less.

**[0098]** Pearlite has a unique lamellar structure, so can be discerned by observation by an SEM or optical microscope. By calculating the region of the lamellar structure at any cross-section, the area ratio of the pearlite can be found.

**[0099]** Based on theory and principle, cold forgeability is considered to be strongly affected by the rate of coverage of the ferrite grain boundaries by carbides. High precision measurement is sought, but measurement of the rate of coverage of ferrite grain boundaries by carbides in a three-dimensional space requires serial sectioning SEM observation using an FIB to repeatedly cut a sample for observation in a scanning electron microscope or 3D EBSP observation. A massive measurement time is required and technical knowhow has to be built up.

**[0100]** The inventors clarified this and searched for a simpler, higher precision indicator for evaluation and as a result discovered that it is possible to evaluate the cold forgeability by using the ratio of the number of carbides at the ferrite grain boundaries to the number of carbides in the ferrite grains as an indicator and that if the ratio of the number of carbides at the ferrite grain boundaries to the number of carbides in the ferrite grains exceeds 1, the cold forgeability remarkably rises.

**[0101]** Note that, buckling, folding, and twisting of the steel plate occurring at the time of cold forging occur due to localization of strain accompanying the formation of a shear zone, so similarly by forming carbides at the ferrite grain boundaries to reduce the formation of a shear zone and localization of strain, it is possible to suppress buckling, folding, and twisting.

**[0102]** The carbides are observed by a scanning electron microscope. Before observation, the sample for observation of the structure is polished by wet polishing by Emery paper and a diamond abrasive having an average particle size of 1  $\mu\text{m}$ , the observed surface is polished to a mirror finish, then a saturated picric acid-alcohol solution is used to etch the structure.

**[0103]** The magnification of the observation was made 3000X and images of eight fields of 30  $\mu\text{m}$ ×40  $\mu\text{m}$  at a plate thickness 1/4 layer were captured at random. The obtained structural images were analyzed by image analyzing software such as one made by Mitani Shoji (Win ROOF) to measure in detail the areas of the carbides contained in those regions. The circle equivalent diameters ( $=2 \times \sqrt{(\text{area}/3.14)}$ ) were found from the areas of the carbides and the average value was made the particle size of the carbides.

**[0104]** Note that, to keep down the effect of measurement error due to noise, carbides with an area of 0.01  $\mu\text{m}^2$  or less are excluded from the coverage of the evaluation.

**[0105]** The number of carbides which present at the ferrite grain boundaries are counted, the number of carbides at the grain boundaries are subtracted from the total number of carbides, and the number of carbides in the ferrite grains are found. Based on the measured number, the number ratio of carbides at the grain boundaries with respect to the carbides inside the ferrite grains is calculated.

**[0106]** By making as the structure after annealing a structure with ferrite grains of a size of 3.0  $\mu\text{m}$  to 50.0  $\mu\text{m}$ , it is possible to improve the cold forgeability. If the size of the ferrite grains is less than 3  $\mu\text{m}$ , the hardness increases and fractures and cracks easily form at the time of cold forging, so the ferrite grain size is preferably 3.0  $\mu\text{m}$  or more. More preferably it is 7.5  $\mu\text{m}$  or more.

**[0107]** On the other hand, if the ferrite grain size is over 50.0  $\mu\text{m}$ , the number of carbides on the crystal grain boundaries suppressing the propagation of slip is decreased and the cold forgeability falls, so the ferrite grain size is preferably 50.0  $\mu\text{m}$  or less. More preferably it is 37.9  $\mu\text{m}$  or less.

**[0108]** The ferrite grain size is measured by using the above-mentioned procedure to polish the observed surface of the sample for observation of structure to a mirror finish, then observing the structure of the observed surface etched by a 3% nitric acid-alcohol solution by an optical microscope or scanning electron microscope and applying the line segment method to the captured image.

**[0109]** By making the Vickers hardness of the steel plate 100HV to 180HV, it is possible to improve the cold forgeability and impact resistance characteristic after carburizing, quenching, and tempering. If the Vickers hardness is less than 100HV, buckling easily occurs during cold forging, folding and twisting occur at the buckled part, and the impact resistance characteristic falls, so the Vickers hardness is made 100HV or more. Preferably it is 110HV or more.

**[0110]** On the other hand, if the Vickers hardness exceeds 180HV, the ductility falls, internal cracking easily occurs at the time of cold forging, and the impact resistance characteristic deteriorates, so the Vickers hardness is made 180HV or less. Preferably it is 170HV or less.

**[0111]** Next, the method of evaluation of the cold forgeability will be explained.

**[0112]** FIGS. 1A to 1C schematically show an outline of the cold forging test and form of a crack introduced by cold forging. FIG. 1A shows a disk-shaped test material cut out from a hot rolled steel plate, FIG. 1B shows the shape of a test material after cold forging, and FIG. 1C shows the cross-sectional shape of a cold forged test material.

**[0113]** As shown in FIGS. 1A to 1C, from a plate thickness 5.2 mm hot rolled steel plate, a diameter 70 mm disk-shaped test material 1 was cut out (see FIG. 1A) and deep drawn so as to prepare a cup-shaped test material with a bottom surface of a diameter of 30 mm (not shown). Next, a one shot forming press made by Mori Ironworks was used to thicken the vertical wall parts of a cup-shaped test material by a thickening ratio of 1.54 (=8 mm/5.2 mm) (cold forging) to prepare a cup-shaped test material 2 with a diameter of 30 mm, a height of 30 mm, and a vertical wall thickness of 8 mm (see FIG. 1B).

**[0114]** The thickened cup-shaped test material 2 is cut by a wire cut electrical discharge machine made by FANUC so that the cross-section of the diameter part appeared (see FIG. 1C). The cut surface is polished to a mirror finish and the presence of a fracture 3 at the cut surface was confirmed. The ratio of the maximum length of fracture L present at the vertical wall parts to the thickness of the vertical wall part after thickening (=maximum length of fracture L/thickness of vertical wall part after thickening 8 mm) is measured. This measured value is used to evaluate the cold forgeability.

**[0115]** Note that, even if the initial plate thickness is other than 5.2 mm, if adjusting the diameter of the cut out disk-shaped test material so that the height of the vertical wall after thickening becomes 30 mm and forming the material by a thickening ratio of the same 1.54, it is possible to reproduce the results of evaluation without regard as to the initial plate thickness, so the hot rolled steel plate covered by the present invention is not limited to a plate thickness 5.2 mm hot rolled steel plate. The present invention can improve the cold forgeability and the impact resistance characteristic after carburizing, quenching, and tempering even in a general plate thickness (2 to 15 mm) hot rolled steel plate.

**[0116]** Next, the method of production of the present invention will be explained. The technical idea of the method of production of the present invention is to integrally manage the rolling conditions and annealing conditions when producing steel plate from a steel slab of the above-mentioned chemical composition so as to improve the cold forgeability and the impact resistance characteristic after carburizing, quenching, and tempering.

**[0117]** The features of the method of production of the present invention will be explained next.

#### Features of Hot Rolling

**[0118]** Molten steel having the required chemical composition is continuously cast into a slab. The slab is used for hot rolling as is in accordance with an ordinary method or is cooled once, then heated and used for hot rolling. The finish hot rolling is ended in the 650°C to 950°C temperature region. The hot rolled steel plate after finish rolling is cooled on the ROT and coiled by a coiling temperature of 400°C to 600°C.

#### Features of Annealing

**[0119]** The hot rolled steel plate is pickled, then held at two temperature regions as two-stage step type annealing, but at that time, in the first stage annealing, the hot rolled steel plate is heated until the annealing temperature by a 30°C/hour to 150°C/hour heating rate and held at a 650°C to 720°C temperature region for 3 hours to 60 hours for annealing.

**[0120]** At the next second stage annealing, the hot rolled steel plate is heated until the annealing temperature by a 1°C/hour to 80°C/hour heating rate and held at a 725°C to 790°C temperature region for 3 hours to 50 hours for annealing.

**[0121]** Next, the annealed hot rolled steel plate is cooled down to 650°C by a cooling rate of 1°C/hour to 100°C/hour, then is cooled down to room temperature.

**[0122]** Due to the linkage between these hot rolling conditions and annealing conditions, low carbon steel plate excellent in cold forgeability and impact resistance characteristic after carburizing, quenching, and tempering can be obtained.

**[0123]** Below, the conditions of steps of the method of production of the present invention will be specifically explained.

## Hot Rolling

**[0124]**

5           Finish hot rolling temperature: 650°C to 950°C  
           Coiling temperature: 400°C to 600°C

10 **[0125]** Molten steel having the required chemical composition is continuously cast into a slab. The slab is used for hot rolling as is or cooled once, then heated. The finish hot rolling is ended in the 650°C to 950°C temperature region. The hot rolled steel plate is coiled at 400°C to 600°C.

**[0126]** The slab heating temperature is preferably 1300°C or less, while the heating time where the slab is held at a temperature of the slab surface layer of 1000°C or more is preferably 7 hours or less.

15 **[0127]** If the heating temperature exceeds 1300°C or the heating time exceeds 7 hours, the decarburization of the slab surface layer becomes remarkable. At the time of heating before hardening, the austenite grains of the surface layer abnormally grow and the impact resistance characteristic falls, so the heating temperature is preferably 1300°C or less and the heating time is preferably 7 hours or less. More preferably, the heating temperature is 1280°C or less, while the heating time is 6 hours or less.

20 **[0128]** The finish hot rolling is ended at 650°C to 950°C in temperature. If the finish hot rolling temperature is less than 650°C, the rolling load remarkably rises due to the increase of the deformation resistance of the steel material. Furthermore, the amount of roll wear increases and the productivity falls, so the finish hot rolling temperature is made 650°C or more. Preferably it is 680°C or more.

25 **[0129]** On the other hand, if the finish hot rolling temperature exceeds 950°C, bulky scale is formed during passage through the ROT (Run Out Table). Due to the scale, flaws form at the surface of the steel plate. At the time of cold forging and/or at the time when an impact load is applied after carburizing, quenching, and tempering, cracks form starting from the flaws and the impact resistance characteristic falls, so the finish hot rolling temperature is made 950°C or less. Preferably it is 920°C or less.

30 **[0130]** The cooling rate when cooling the hot rolled steel plate on the ROT is preferably 10°C/sec to 100°C/sec. If the cooling rate is less than 10°C/sec, in the middle of the cooling, it is not possible to suppress the formation of bulky scale and the formation of flaws due to the same and the impact resistance characteristic falls, so the cooling rate is preferably 10°C/sec or more. More preferably it is 20°C/sec or more.

**[0131]** On the other hand, if cooling the hot rolled steel plate from the surface layer to the inside part of the steel plate by a cooling rate of over 100°C/sec, the outermost layer part is excessively cooled and bainite, martensite, and other low temperature transformed structures are formed at the outermost layer part.

35 **[0132]** After coiling, when the 100°C to room temperature hot rolled steel plate is paid out, fine cracks form at low temperature transformed structures. It is difficult to remove the cracks in the following pickling process and cold rolling process. At the time of cold forging and/or at the time when an impact load is applied after carburizing, quenching, and tempering, cracks grow starting from those cracks and invite a drop in the impact resistance characteristic, so the cooling rate is preferably 100°C/sec or less. More preferably it is 80°C/sec or less.

40 **[0133]** Note that, the cooling rate indicates the cooling ability received from the cooling facilities in a water spray section at the time when being cooled on the ROT down to the target temperature of coiling from the time when the hot rolled steel plate after finish hot rolling is water cooled at a water spray section after passing through a non-water spray section. It does not show the average cooling rate from the starting point of water spray to the temperature at which the steel plate is coiled up by the coiler.

45 **[0134]** The coiling temperature is made 400°C to 600°C. This is a temperature lower than the general coiling temperature. By coiling the hot rolled steel plate produced in the above-mentioned condition in this temperature range, the structure of the steel plate can be made a bainite structure in which carbides are dispersed in fine ferrite.

**[0135]** If the coiling temperature is less than 400°C, the austenite, which was not transformed before coiling, transforms to hard martensite. At the time of discharging the coiled hot rolled steel plate, cracks form at the surface layer and the impact resistance characteristics fall, so the coiling temperature is made 400°C or more. Preferably, it is 430°C or more.

50 **[0136]** On the other hand, if the coiling temperature exceeds 600°C, pearlite with a large lamellar spacing is formed, high thermal stability bulky needle shaped carbides are formed, and needle shaped carbides remain even after two-stage step type annealing. At the time of cold forging, cracks occur and grow starting from these needle shaped carbides, so the coiling temperature is made 600°C or less. Preferably it is 570°C or less.

55 **[0137]** The hot rolled steel plate produced under the above conditions was pickled, then held in two temperature regions for two-stage step type annealing. By treating the hot rolled steel plate by two-stage step type annealing, the carbides are controlled in stability and the formation of carbides at the ferrite grain boundaries is promoted.

**[0138]** First, the technical idea of two-stage step type annealing will be explained.

**[0139]** By performing the first stage annealing in a temperature region of the Ac1 point or less, the carbides are made

to coarsen and added metal elements are made to concentrate to raise the thermal stability of the carbides. After that, the steel is raised to the Ac1 or more in temperature to form austenite in the structure, the fine carbides in the ferrite grains are made to dissolve into the austenite, and coarse carbides are left in the austenite.

[0140] By the subsequent gradual cooling, the austenite is transformed to ferrite and raises the concentration of carbon in the austenite. Along with gradual cooling, carbon atoms are adsorbed at the carbides remaining in the austenite, the carbides and austenite cover the grain boundaries of the ferrite, and, finally, it becomes possible to form a structure with a large amount of carbides present at the ferrite grain boundaries. For this reason, it is clear that the structure of the present invention cannot be formed by just simple annealing.

[0141] Below, the specific annealing conditions will be explained.

#### First Stage Annealing

##### [0142]

Heating rate up to annealing temperature: 30°C/hour to 150°C/hour

Annealing temperature: 650°C to 720°C

Holding time at annealing temperature: 3 hours to 60 hours

[0143] The heating rate up to the first stage annealing temperature is made 30°C/hour to 150°C/hour. If the heating rate is less than 30°C/hour, time is required for raising the temperature and the productivity falls, so the heating rate is made 30°C/hour or more. Preferably, it is 40°C/hour or more.

[0144] On the other hand, if the heating rate is over 150°C/hour, the temperature difference between the outer circumferential part and the inside part of the coil increases, scratches and seizing occur due to the difference in heat expansion, and relief shapes are formed at the steel plate surface. At the time of cold forging, cracks occur starting from the relief shapes and invite a drop in cold forgeability and a drop in impact resistance characteristic after carburizing, quenching, and tempering, so the heating rate is made 150°C/hour or less. Preferably, it is made 120°C/hour or less.

[0145] The annealing temperature in the first stage annealing (first stage annealing temperature) is made 650°C to 720°C. If the first stage annealing temperature is less than 650°C, the carbides becomes insufficient in stability and it becomes difficult to form carbides remaining in the austenite in the second stage annealing, so the first stage annealing temperature is made 650°C or more. Preferably it is 670°C or more.

[0146] On the other hand, if the annealing temperature exceeds 720°C, before the carbides rise in stability, austenite is formed and it becomes impossible to control the above-mentioned changes in structure, so the annealing temperature is made 720°C or less. Preferably it is 700°C or less.

[0147] The holding time in the first stage annealing (first stage holding time) is made 3 hours to 60 hours. If the first stage holding time is less than 3 hours, the carbides become insufficient in stability and it becomes difficult to form carbides remaining in the second stage annealing, so the first stage holding time is made 3 hours or more. Preferably it is 10 hours or more.

[0148] On the other hand, if the first stage holding time exceeds 60 hours, no further improvement in stability of the carbides can be expected. Furthermore, a drop in productivity is invited, so the first stage holding time is made 60 hours or less. Preferably it is 50 hours or less.

#### Second Stage Annealing

##### [0149]

Heating rate up to annealing temperature: 1°C/hour to 80°C/hour

Annealing temperature: 725°C to 790°C

Holding time at annealing temperature: 3 hours to 50 hours

[0150] After finishing being held at the first stage annealing, the hot rolled steel plate is heated up to the annealing temperature by a heating rate of 1°C/hour to 80°C/hour. If cooling without performing this second stage annealing, the ferrite grain size does not become larger and the ideal structure cannot be obtained.

[0151] In the second stage annealing, austenite is produced and grows from the ferrite grain boundaries. By slowing the heating rate, it is possible to suppress formation of nuclei of austenite. In the structure obtained after gradual cooling, it becomes possible to raise the rate of coverage of the grain boundaries of the carbides. For this reason, the heating rate at the second stage annealing is preferably small.

[0152] If the heating rate is less than 1°C/hour, time is required for raising the temperature and the productivity falls, so the heating rate is made 1°C/hour or more. Preferably it is 10°C/hour or more.

**[0153]** On the other hand, if the heating rate exceeds 80°C/hour, the temperature difference between the outer circumferential part and inside part of the coil increases. Due to the large difference in heat expansion due to deformation, scratches and seizing occur and relief shapes are formed at the surface of the steel plate. At the time of cold forging, cracks form starting from the relief shapes leading to a drop in cold forgeability and a drop in impact resistance characteristic after carburizing, quenching, and tempering, so the heating rate is made 80°C/hour or less.

**[0154]** The annealing temperature in the second stage annealing (second stage annealing temperature) is made 725°C to 790°C. If the second stage annealing temperature is less than 725°C, the amount of production of austenite becomes smaller. After cooling after the second stage annealing, the number ratio of carbides at the ferrite grain boundaries falls and, further, the ferrite grain size becomes smaller. For this reason, the second stage annealing temperature is made 725°C or more. Preferably it is 735°C or more.

**[0155]** On the other hand, if the second stage annealing temperature exceeds 790°C, it becomes difficult to form carbides remaining in the austenite and control to the above-mentioned change of structure becomes difficult, so the second stage annealing temperature is made 790°C or less. Preferably it is 780°C or less.

**[0156]** The holding time in the second stage annealing (second stage holding time) is made 1 hour to 50 hours. If the second stage holding time is less than 1 hour, the amount of austenite which is produced is small, the carbides in the ferrite grains are not sufficiently dissolved, it becomes difficult to increase the number ratio of carbides at the ferrite grain boundaries, and, further, the ferrite grains become smaller in size, so the second stage holding time is made 1 hour or more. Preferably, it is 5 hours or more.

**[0157]** On the other hand, if the second stage holding time exceeds 50 hours, it is difficult to make carbides remain in the austenite, so the second stage holding time is made 50 hours or less. Preferably it is 45 hours.

#### Cooling After Annealing

**[0158]**

Cooling stop temperature: 650°C

Cooling rate: 1°C/hour to 100°C/hour

**[0159]** After finishing being held at the second stage annealing, the annealed hot rolled steel plate is gradually cooled down to 650°C by a cooling rate of 1°C/hour to 100°C/hour. If the stop temperature of gradual cooling exceeds 650°C, due to the cooling rate subsequently exceeding 100°C/hour down to room temperature, nontransformed austenite transforms to pearlite or bainite, the hardness increases, and the cold forgeability falls, so the cooling stop temperature is made 650°C.

**[0160]** To cool the austenite formed in the second stage annealing and transform it to ferrite and to make carbon be adsorbed at the carbides remaining in the austenite, a slower cooling rate is preferable. If the cooling rate is less than 1°C/hour, the time required for cooling increases and the productivity falls, so the cooling rate is made 1°C/hour or more. Preferably it is 10°C/hour or more.

**[0161]** On the other hand, if the cooling rate exceeds 100°C/hour, austenite transforms to pearlite and the steel plate increases in hardness so a drop in cold forgeability and a drop in impact resistance characteristics after carburizing, quenching, and tempering are invited, so the cooling rate is made 100°C/hour or less. Preferably it is 90°C/hour.

**[0162]** Here, the cooling stop temperature is the temperature where the cooling rate should be used for control. If cooling down to 650°C by a cooling rate of 1°C/hour to 100°C/hour, the cooling down to 650°C or less is not particularly limited.

**[0163]** Note that, the atmosphere of the annealing is not limited to any specific atmosphere. For example, it may be any of an atmosphere of 95% or more of nitrogen, an atmosphere of 95% or more of hydrogen, and an air atmosphere.

**[0164]** As explained above, according to the method of the present invention of integrally managing the hot rolling conditions and annealing conditions and controlling the structure of the steel plate, it is possible to produce low carbon steel plate exhibiting excellent cold forgeability in cold forging combining drawing and thickening and, furthermore, excellent in impact resistance characteristics after carburizing, quenching, and tempering.

#### Examples

**[0165]** Next, examples will be explained, but the levels in the examples are illustrations of conditions employed for confirming the workability and effects of the present invention. The present invention is not limited to these illustrations of conditions. The present invention can employ various conditions so long as not deviating from the gist of the present invention and achieving the object of the present invention.

**[0166]** A continuously cast slab (steel ingot) having a chemical composition shown in Table 1 was heated at 1240°C for 1.8 hours, then was used for hot rolling. The finish hot rolling was ended at 890°C, the steel was cooled on a ROT

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by a 45°C/sec cooling rate down to 520°C and was coiled up at 510°C to produce a hot rolled coil with a plate thickness of 5.2 mm.

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Table 1

| No. | Chemical composition (mass%) |      |      |        |        |       |       |       |        |        |        |        | Remarks           |
|-----|------------------------------|------|------|--------|--------|-------|-------|-------|--------|--------|--------|--------|-------------------|
|     | C                            | Si   | Mn   | P      | S      | Al    | Cr    | Mo    | N      | O      | Ti     | B      |                   |
| A   | 0.12                         | 0.07 | 0.85 | 0.0154 | 0.0084 | 0.031 | 0.527 | 0.636 | 0.0068 | 0.0003 | 0.0095 | 0.0004 | Invention steel   |
| B   | 0.13                         | 0.03 | 0.76 | 0.0069 | 0.0046 | 0.011 | 1.483 | 0.017 | 0.0057 | 0.0122 | 0.0039 | 0.0001 | Invention steel   |
| C   | 0.17                         | 0.18 | 0.34 | 0.0027 | 0.0019 | 0.004 | 0.996 | 0.204 | 0.0002 | 0.0030 | 0.0004 | 0.0000 | Invention steel   |
| D   | 0.21                         | 0.17 | 0.81 | 0.0133 | 0.0073 | 0.032 | 0.563 | 0.173 | 0.0086 | 0.0166 | 0.0030 | 0.0002 | Invention steel   |
| E   | 0.23                         | 0.24 | 0.64 | 0.0169 | 0.0095 | 0.046 | 1.934 | 0.731 | 0.0094 | 0.0063 | 0.0043 | 0.0003 | Invention Steel   |
| F   | 0.25                         | 0.06 | 0.84 | 0.0189 | 0.0099 | 0.062 | 1.043 | 0.195 | 0.0048 | 0.0196 | 0.0033 | 0.0002 | Invention Steel   |
| G   | 0.26                         | 0.19 | 0.45 | 0.0112 | 0.0075 | 0.017 | 1.024 | 0.003 | 0.0053 | 0.0176 | 0.0088 | 0.0002 | Invention Steel   |
| H   | 0.30                         | 0.05 | 0.95 | 0.0100 | 0.0012 | 0.091 | 0.586 | 0.591 | 0.0034 | 0.0170 | 0.0058 | 0.0004 | Invention Steel   |
| I   | 0.34                         | 0.28 | 0.92 | 0.0043 | 0.0017 | 0.078 | 1.905 | 0.860 | 0.0086 | 0.0188 | 0.0013 | 0.0000 | Invention Steel   |
| J   | 0.36                         | 0.01 | 0.51 | 0.0162 | 0.0006 | 0.069 | 0.705 | 0.943 | 0.0016 | 0.0125 | 0.0093 | 0.0002 | Invention Steel   |
| K   | 0.39                         | 0.10 | 0.85 | 0.0013 | 0.0074 | 0.033 | 1.635 | 0.736 | 0.0131 | 0.0143 | 0.0049 | 0.0002 | Invention Steel   |
| L   | 0.07                         | 0.21 | 0.76 | 0.0166 | 0.0005 | 0.013 | 0.609 | 0.842 | 0.0050 | 0.0163 | 0.0086 | 0.0004 | Comparative Steel |
| M   | 0.11                         | 0.19 | 0.78 | 0.0211 | 0.0069 | 0.002 | 1.379 | 0.941 | 0.0183 | 0.0186 | 0.0087 | 0.0003 | Comparative Steel |
| N   | 0.14                         | 0.24 | 0.79 | 0.0169 | 0.0020 | 0.040 | 1.328 | 1.071 | 0.0174 | 0.0155 | 0.0063 | 0.0002 | Comparative Steel |
| O   | 0.15                         | 0.13 | 0.58 | 0.0018 | 0.0098 | 0.031 | 0.449 | 0.291 | 0.0181 | 0.0171 | 0.0024 | 0.0003 | Comparative Steel |
| P   | 0.20                         | 0.19 | 0.31 | 0.0025 | 0.0090 | 0.108 | 0.525 | 0.762 | 0.0195 | 0.0172 | 0.0084 | 0.0003 | Comparative Steel |
| Q   | 0.24                         | 0.19 | 1.09 | 0.0196 | 0.0081 | 0.057 | 0.774 | 0.066 | 0.0066 | 0.0017 | 0.0039 | 0.0003 | Comparative Steel |
| R   | 0.25                         | 0.25 | 0.90 | 0.0099 | 0.0109 | 0.100 | 0.849 | 0.652 | 0.0178 | 0.0067 | 0.0017 | 0.0003 | Comparative Steel |
| S   | 0.27                         | 0.31 | 0.36 | 0.0050 | 0.0063 | 0.094 | 0.822 | 0.006 | 0.0019 | 0.0099 | 0.0019 | 0.0003 | Comparative Steel |
| T   | 0.29                         | 0.26 | 0.63 | 0.0120 | 0.0049 | 0.003 | 2.236 | 0.011 | 0.0153 | 0.0092 | 0.0073 | 0.0001 | Comparative Steel |
| U   | 0.45                         | 0.19 | 0.64 | 0.0009 | 0.0025 | 0.072 | 1.150 | 0.008 | 0.0109 | 0.0154 | 0.0063 | 0.0004 | Comparative Steel |
| V   | 0.18                         | 0.16 | 0.28 | 0.0129 | 0.0100 | 0.048 | 0.917 | 0.961 | 0.0085 | 0.0001 | 0.0005 | 0.0002 | Comparative Steel |
| W   | 0.15                         | 0.21 | 0.89 | 0.0076 | 0.0009 | 0.091 | 1.293 | 0.005 | 0.0058 | 0.0209 | 0.0042 | 0.0000 | Comparative Steel |
| X   | 0.25                         | 0.26 | 0.46 | 0.0070 | 0.0052 | 0.029 | 1.089 | 0.610 | 0.0162 | 0.0161 | 0.0105 | 0.0001 | Comparative Steel |

(continued)

| No. | Chemical composition (mass%) |      |      |        |        |       |       |       |        |        |        |        | Remarks           |
|-----|------------------------------|------|------|--------|--------|-------|-------|-------|--------|--------|--------|--------|-------------------|
|     | C                            | Si   | Mn   | P      | S      | Al    | Cr    | Mo    | N      | O      | Ti     | B      |                   |
| Y   | 0.28                         | 0.20 | 0.76 | 0.0112 | 0.0026 | 0.083 | 1.193 | 0.713 | 0.0171 | 0.0083 | 0.0030 | 0.0006 | Comparative Steel |
| Z   | 0.25                         | 0.14 | 0.60 | 0.0033 | 0.0004 | 0.047 | 0.744 | 0.176 | 0.0208 | 0.0035 | 0.0054 | 0.0004 | Comparative Steel |

**[0167]** The hot rolled coil was pickled, the coil was loaded into a box-type annealing furnace, the atmosphere was controlled to 95% hydrogen-5% nitrogen, then the coil was heated from room temperature up to 705°C by a heating rate of 100°C/hour, was held at 705°C for 36 hours to make the temperature distribution inside the coil uniform, then was heated by a 5°C/hour heating rate up to 760°C, and, furthermore, was held at 760°C for 10 hours, then was cooled down to 650°C by a 10°C/hour cooling rate, then was furnace cooled down to room temperature to prepare a sample for evaluation of the characteristics.

**[0168]** The structure of the sample was observed by the above-mentioned method. The crack length at the sample after cold forging was measured by the above-mentioned method.

**[0169]** The carburization of the thickened sample was performed by gas carburization. To make the carbon disperse from the inside of the furnace atmosphere gas through the surface layer of the sample to the inside of the steel, the sample was treated by holding it at 940°C for 120 minutes inside a furnace controlled to a carbon potential of 0.5 mass% C, then was furnace cooled down to room temperature.

**[0170]** Next, the sample was heated from room temperature to 840°C, then was held for 20 minutes and quenched in 60°C oil. The hardened sample was held at 170°C for 60 minutes, then air cooled for tempering to prepare a carburized, quenched, and tempered sample.

**[0171]** The carburized, quenched, and tempered sample was evaluated for impact resistance by a drop weight test. FIG. 2 schematically shows an outline of the drop weight test for evaluating the impact resistance characteristic of a carburized, quenched, and tempered sample. The bottom of the cup of a carburized, quenched, and tempered cup-shaped sample 4 was fastened by a fixture. On a side surface of the cup, a weight 2 kg dropping weight (top side width: 50 mm, bottom side width: 10 mm, height: 80 mm, and length: 110 mm) was allowed to freely drop from 4 m above to give an approximately 80J impact on the vertical wall part of the sample 4. The sample was examined for the presence of any cracking and was evaluated for the impact resistance characteristic.

**[0172]** A sample with no fracture or breakage observed as a result of free dropping was evaluated as excellent in impact resistance characteristics, that is, "OK", while a sample with a fracture or breakage observed was evaluated as inferior in impact resistance, that is, "NG".

**[0173]** Table 2 shows the results of measurement and results of evaluation of the carbide size, pearlite area ratio, ferrite grain size, Vickers hardness, ratio of the number of carbides at the ferrite grain boundaries to number of carbides in the ferrite grains, ratio of maximum crack length to plate thickness at the vertical wall parts, and impact resistance characteristic in the prepared samples.

Table 2

|     | Carbide size ( $\mu\text{m}$ ) | Ferrite grain size ( $\mu\text{m}$ ) | Pearlite area rate (%) | Vickers hardness (HV) | No. of carbides at grain boundaries/No. of carbides inside grains | Ratio of maximum crack length (%) | Impact resistance characteristic | Remarks           |
|-----|--------------------------------|--------------------------------------|------------------------|-----------------------|-------------------------------------------------------------------|-----------------------------------|----------------------------------|-------------------|
| A-1 | 1.11                           | 23                                   | 1.2                    | 106.0                 | 8.67                                                              | 1.5                               | OK                               | Invention Steel   |
| B-1 | 0.92                           | 18.5                                 | 0.9                    | 106.1                 | 5.72                                                              | 2.0                               | OK                               | Invention Steel   |
| C-1 | 0.87                           | 23.5                                 | 1.3                    | 107.4                 | 4.87                                                              | 2.3                               | OK                               | Invention Steel   |
| D-1 | 1.07                           | 19.4                                 | 1.3                    | 117.4                 | 7.65                                                              | 2.3                               | OK                               | Invention Steel   |
| E-1 | 0.78                           | 15                                   | 1.3                    | 126.7                 | 1.08                                                              | 3.8                               | OK                               | Invention Steel   |
| F-1 | 0.99                           | 17.2                                 | 0.7                    | 115.7                 | 6.75                                                              | 2.4                               | OK                               | Invention Steel   |
| G-1 | 0.88                           | 19.5                                 | 0.3                    | 117.5                 | 4.90                                                              | 2.9                               | OK                               | Invention Steel   |
| H-1 | 1.09                           | 17.7                                 | 0.5                    | 118.0                 | 8.44                                                              | 2.2                               | OK                               | Invention Steel   |
| I-1 | 0.84                           | 13.1                                 | 0.5                    | 140.2                 | 1.76                                                              | 3.4                               | OK                               | Invention Steel   |
| J-1 | 0.98                           | 18.3                                 | 1.1                    | 114.7                 | 6.68                                                              | 2.3                               | OK                               | Invention Steel   |
| K-1 | 0.9                            | 14.9                                 | 0.7                    | 127.3                 | 5.63                                                              | 3.3                               | OK                               | Invention Steel   |
| L-1 | 1.08                           | 26.2                                 | 0.6                    | 92.2                  | 9.29                                                              | 15.5                              | NG                               | Comparative Steel |
| M-1 | 0.96                           | 19.7                                 | 1.1                    | 114.4                 | 0.12                                                              | 15.4                              | NG                               | Comparative Steel |
| N-1 | 0.96                           | 18.1                                 | 8.8                    | 191.7                 | 0.18                                                              | 22.9                              | NG                               | Comparative Steel |

(continued)

|     | Carbide size<br>size (μm) | Ferrite grain size<br>(μm) | Pearlite area<br>rate (%) | Vickers hardness<br>(HV) | No. of carbides at grain<br>boundaries/No. of carbides inside<br>grains | Ratio of maximum<br>crack length (%) | Impact resistance<br>characteristic | Remarks           |
|-----|---------------------------|----------------------------|---------------------------|--------------------------|-------------------------------------------------------------------------|--------------------------------------|-------------------------------------|-------------------|
| O-1 | 1.06                      | 22.7                       | 0.1                       | 107.4                    | 7.16                                                                    | 1.8                                  | NG                                  | Comparative Steel |
| P-1 | 0.97                      | 25.2                       | 0.6                       | 110.0                    | 0.61                                                                    | 13.7                                 | NG                                  | Comparative Steel |
| Q-1 | 1.08                      | 18.1                       | 0.9                       | 123.9                    | 8.00                                                                    | 2.6                                  | NG                                  | Comparative Steel |
| R-1 | 1.03                      | 17                         | 1.2                       | 128.8                    | 7.06                                                                    | 18.8                                 | NG                                  | Comparative Steel |
| S-1 | 0.85                      | 21.4                       | 1.0                       | 124.3                    | 4.23                                                                    | 13.6                                 | NG                                  | Comparative Steel |
| T-1 | 0.69                      | 14.1                       | 13.1                      | 232.5                    | 0.24                                                                    | 26.2                                 | NG                                  | Comparative Steel |
| U-1 | 0.89                      | 15.4                       | 1.5                       | 135.0                    | 21.15                                                                   | 3.2                                  | NG                                  | Comparative Steel |
| V-1 | 0.9                       | 25.8                       | 0.3                       | 105.3                    | 0.67                                                                    | 11.5                                 | NG                                  | Comparative Steel |
| W-1 | 0.94                      | 17.1                       | 0.7                       | 122                      | 0.82                                                                    | 14.3                                 | NG                                  | Comparative Steel |
| X-1 | 0.89                      | 19.3                       | 0.1                       | 121.8                    | 0.51                                                                    | 15.3                                 | NG                                  | Comparative Steel |
| Y-1 | 0.95                      | 16.1                       | 0.4                       | 126.8                    | 6.06                                                                    | 15.4                                 | NG                                  | Comparative Steel |
| Z-1 | 1                         | 19.1                       | 0.8                       | 116.1                    | 0.68                                                                    | 14.2                                 | NG                                  | Comparative Steel |

**[0174]** As shown in Table 2, in Invention Steels A-1, B-1, C-1, D-1, E-1, F-1, G-1, H-1, I-1, J-1, and K-1, in each case, the ratio of the number of carbides at the ferrite grain boundaries to the number of carbides in the ferrite grains is over 1, the Vickers hardness is 100HV to 180HV, and the cold forgeability and impact resistance characteristics after carburizing, quenching, and tempering are excellent.

**[0175]** As opposed to this, in Comparative Steel L-1, the amount of C is low and the hardness before cold forging is less than 100HV, so the cold forgeability is low. In Comparative Steels M-1, P-1, and Z-1, P, Al, and N are excessively contained and, at the second stage annealing, the amount of segregation at the  $\gamma/\alpha$  interfaces is large, so formation of carbides at the grain boundaries is suppressed.

**[0176]** In Comparative Steel S-1, Si is excessively contained and ductility of the ferrite is low, so the cold forgeability is low. In Comparative Steels N-1 and T-1, Mo and Cr are excessively contained, so carbides finely disperse inside the ferrite grains and the hardness exceeds 180HV. In Comparative Steel Q-1, Mn is excessively contained, so the impact resistance characteristic after carburizing, quenching, and tempering is remarkably low.

**[0177]** In Comparative Steel O-1, the amount of Cr is small and the austenite grains at the surface layer abnormally coarsen at the time of carburization, so the impact resistance is low. In Comparative Steel R-1, S is excessively contained, so coarse MnS is formed in the steel and the cold forgeability is low. In Comparative Steel U-1, C is excessively contained, so coarse carbides form inside the thickened layer of the steel and coarse carbides remain even after the carburizing and quenching, so the impact resistance characteristic is low.

**[0178]** In Comparative Steel V-1, the amount of Mn is small and the carbides are hard to raise in stability, so the cold forgeability and impact resistance characteristic after carburizing, quenching, and tempering are low. In Comparative Steels W-1 and X-1, O and Ti are excessively contained, so the oxides and TiC present in the ferrite grains become site for formation of carbides in gradual cooling after dual phase region annealing, the formation of carbides at the grain boundaries is suppressed, and the cold forgeability is low. In Comparative Steel Y-1, B is excessively contained, so the cold forgeability is low.

**[0179]** Next, to investigate the effects of the manufacturing conditions, slabs having the chemical compositions A, B, C, D, E, F, G, H, I, J, and K shown in Table 1 were hot rolled and annealed under the conditions shown in Table 3 to prepare annealed samples of hot rolled plates of a thickness of 5.2 mm.

**[0180]** Table 4 shows the results of measurement and results of evaluation of the carbide size, pearlite area ratio, ferrite grain size, Vickers hardness, ratio of the number of carbides at the ferrite grain boundaries to number of carbides in the ferrite grains, ratio of maximum crack length to plate thickness at the vertical wall parts, and impact resistance characteristics in the prepared samples.

Table 3

|     | Hot rolling conditions |                      |                               |                            |                    | Annealing conditions    |                    |                      |                         |                    |                      | Remarks |             |
|-----|------------------------|----------------------|-------------------------------|----------------------------|--------------------|-------------------------|--------------------|----------------------|-------------------------|--------------------|----------------------|---------|-------------|
|     | Heating temp. (°C)     | Soaking time (hours) | Finish hot rolling temp. (°C) | ROT cooling rate (°C/ sec) | Coiling temp. (°C) | 1st stage               |                    |                      | 2nd stage               |                    |                      |         |             |
|     |                        |                      |                               |                            |                    | Heating rate (°C/ hour) | Holding temp. (°C) | Holding time (hours) | Heating rate (°C/ hour) | Holding temp. (°C) | Holding time (hours) |         |             |
| A-2 | -                      | -                    | 837.1                         | 63                         | 449.2              | 143.7                   | 653.1              | 44.1                 | 48.1                    | 745.2              | 49.7                 | 26.8    | Inv. steel  |
| B-2 | 1162                   | 0.5                  | 905                           | 35                         | 409.3              | 101.3                   | 706.5              | 32.9                 | 2.2                     | 773.5              | 13.6                 | 84.6    | Inv. steel  |
| C-2 | 1196                   | 2.5                  | 882.3                         | 64                         | 388                | 67.9                    | 695.6              | 36.5                 | 19.5                    | 735.7              | 20.7                 | 33.8    | Comp. steel |
| D-2 | 1060                   | 5.6                  | 826                           | 21                         | 496.8              | 55.9                    | 683.2              | 49.2                 | 31.4                    | 789                | 41.4                 | 99.5    | Inv. steel  |
| E-2 | 1241                   | 3.4                  | 639                           | 33                         | 526.7              | 84.5                    | 687.5              | 43                   | 40.5                    | 775.1              | 4.6                  | 72.4    | Comp. steel |
| F-2 | 1271                   | 0.8                  | 714.7                         | 91                         | 412.1              | 71.4                    | 709.2              | 63.1                 | 23.8                    | 769.7              | 14.4                 | 10.8    | Comp. steel |
| G-2 | 1265                   | 5.6                  | 844.4                         | 52                         | 627                | 133.6                   | 671.7              | 44.2                 | 28.9                    | 750                | 39.7                 | 92.1    | Comp. steel |
| H-2 | 1287                   | 5.9                  | 752.9                         | 30                         | 567.5              | 139.4                   | 709                | 22                   | 16.4                    | 731.9              | 28.9                 | 57.7    | Inv. steel  |
| I-2 | 1030                   | 5.6                  | 850.3                         | 100                        | 541.1              | 44.5                    | 695.4              | 51.9                 | 29.9                    | 788.7              | 30.5                 | 76.7    | Inv. steel  |
| J-2 | 1258                   | 0.6                  | 741.9                         | 76                         | 543.9              | 35.9                    | 720                | 33.7                 | 78.8                    | 773                | 1.3                  | 1.4     | Inv. steel  |
| K-2 | 1152                   | 5.9                  | 703                           | 41                         | 516.2              | 44.8                    | 681.1              | 46.5                 | 2.8                     | 721                | 35.3                 | 72      | Comp. steel |
| A-3 | 1138                   | 4.5                  | 829.7                         | 53                         | 472.1              | 85.9                    | 687.2              | 35.8                 | 88                      | 773                | 29.2                 | 92.8    | Comp. steel |
| B-3 | 1254                   | 1.7                  | 717.5                         | 70                         | 526.9              | 42.6                    | 715.1              | 15.6                 | 48                      | 740.3              | 1.8                  | 6.7     | Comp. steel |
| C-3 | 1292                   | 2.5                  | 870.5                         | 35                         | 535.8              | 36.2                    | 669                | 47.7                 | 37.9                    | 784.7              | 15.9                 | 95      | Inv. steel  |
| D-3 | 1010                   | 1.4                  | 812.3                         | 69                         | 403.5              | 124.9                   | 709.2              | 11                   | 72.3                    | 734.5              | 8.8                  | 0.4     | Comp. steel |

(continued)

|     | Hot rolling conditions |                      |                               |                            |                    | Annealing conditions    |                    |                      |                         |                    |                      | Remarks |                                      |
|-----|------------------------|----------------------|-------------------------------|----------------------------|--------------------|-------------------------|--------------------|----------------------|-------------------------|--------------------|----------------------|---------|--------------------------------------|
|     | Heating temp. (°C)     | Soaking time (hours) | Finish hot rolling temp. (°C) | ROT cooling rate (°C/ sec) | Coiling temp. (°C) | 1st stage               |                    |                      | 2nd stage               |                    |                      |         |                                      |
|     |                        |                      |                               |                            |                    | Heating rate (°C/ hour) | Holding temp. (°C) | Holding time (hours) | Heating rate (°C/ hour) | Holding temp. (°C) | Holding time (hours) |         | Cooling rate down to 650°C (°C/hour) |
| E-3 | 1007                   | 0.8                  | 689.5                         | 93                         | 466.5              | 158                     | 700                | 54.6                 | 55.8                    | 775.8              | 45.6                 | 16.7    | Comp. steel                          |
| F-3 | 1062                   | 3.6                  | 656.1                         | 25                         | 567.7              | 126.5                   | 699.9              | 42.7                 | 24.9                    | 731.2              | 29.5                 | 13.1    | Inv. steel                           |
| G-3 | 1137                   | 2.8                  | 851.7                         | 48                         | 446.5              | 94.4                    | 682.2              | 14.8                 | 77.1                    | 757.8              | 42.6                 | 16.4    | Inv. steel                           |
| H-3 | 1089                   | 5.6                  | 767.6                         | 10                         | 468.4              | 146.7                   | 685.1              | 49.1                 | 8                       | 768.9              | 45.6                 | 34.8    | Inv. steel                           |
| I-3 | 1288                   | 1.7                  | 682.3                         | 55                         | 443                | 109.2                   | 683.1              | 39.2                 | 63.7                    | 769.9              | 29.9                 | 116     | Comp. steel                          |
| J-3 | 1037                   | 5.6                  | 879                           | 53                         | 519.9              | 59.1                    | 719.2              | 59.8                 | 77.5                    | 727                | 57                   | 47.3    | Comp. steel                          |
| K-3 | -                      | -                    | 664.6                         | 85                         | 407.9              | 75.7                    | 665.4              | 32                   | 40.2                    | 777                | 21.4                 | 32      | Inv. steel                           |
| A-9 | 1164                   | 2.5                  | 710.6                         | 80                         | 503.2              | 135.8                   | 669.3              | 47.1                 | 71.3                    | 731.3              | 25.8                 | 69.3    | Inv. steel                           |
| B-4 | 1136                   | 4.8                  | 695.9                         | 28                         | 445                | 90.1                    | 701.4              | 21                   | 0.2                     | 776.1              | 42.9                 | 87.4    | Comp. steel                          |
| C-4 | 1046                   | 1.1                  | 667.3                         | 80                         | 405.1              | 54.9                    | 710.4              | 47.8                 | 56.4                    | 804                | 17.1                 | 97.5    | Comp. steel                          |
| D-4 | 1253                   | 4.5                  | 708.1                         | 29                         | 493.9              | 74                      | 737                | 57.3                 | 38.4                    | 755.7              | 33.6                 | 55.4    | Comp. steel                          |
| E-4 | 1018                   | 5.0                  | 870.2                         | 54                         | 560.4              | 141.7                   | 710.9              | 9.2                  | 19.7                    | 748                | 16.2                 | 96.5    | Inv. steel                           |
| F-4 | 1229                   | 6.2                  | 962                           | 71                         | 475.1              | 99.3                    | 672.1              | 24                   | 28.4                    | 736.3              | 24.1                 | 7.9     | Comp. steel                          |
| G-4 | 1139                   | 6.4                  | 749.8                         | 19                         | 535                | 144.8                   | 639                | 39.3                 | 18                      | 783.9              | 32.5                 | 91.3    | Comp. steel                          |
| H-4 | 1119                   | 4.8                  | 731.7                         | 66                         | 456.1              | 13                      | 668.3              | 46.6                 | 55.8                    | 744.7              | 19                   | 43.8    | Comp. steel                          |

(continued)

|     | Hot rolling conditions |                      |                               |                            |                    | Annealing conditions    |                    |                      |                         |                    |                      |                                      | Remarks     |
|-----|------------------------|----------------------|-------------------------------|----------------------------|--------------------|-------------------------|--------------------|----------------------|-------------------------|--------------------|----------------------|--------------------------------------|-------------|
|     | Heating temp. (°C)     | Soaking time (hours) | Finish hot rolling temp. (°C) | ROT cooling rate (°C/ sec) | Coiling temp. (°C) | 1st stage               |                    |                      | 2nd stage               |                    |                      | Cooling rate down to 650°C (°C/hour) |             |
|     |                        |                      |                               |                            |                    | Heating rate (°C/ hour) | Holding temp. (°C) | Holding time (hours) | Heating rate (°C/ hour) | Holding temp. (°C) | Holding time (hours) |                                      |             |
| 1-4 | 1101                   | 4.2                  | 686                           | 33                         | 569.4              | 73.6                    | 656.1              | 31.1                 | 20.3                    | 790.4              | 31.5                 | 29.2                                 | Inv. steel  |
| J-4 | 1042                   | 0.6                  | 750.8                         | 69                         | 545.5              | 40                      | 719.4              | 1.4                  | 71.9                    | 729.1              | 38.3                 | 11.9                                 | Comp. steel |
| K-4 | 1268                   | 4.5                  | 912.2                         | 44                         | 521.5              | 92.5                    | 652.2              | 54.7                 | 39.2                    | 745.5              | 37.4                 | 48.1                                 | Inv. steel  |

Table 4

|     | Carbide size ( $\mu\text{m}$ ) | Ferrite grain size ( $\mu\text{m}$ ) | Pearlite area rate (%) | Vickers hardness (HV) | No. of carbides at grain boundaries/No. of carbides inside grains | Ratio of maximum crack length (%) | Impact resistance characteristic | Remarks           |
|-----|--------------------------------|--------------------------------------|------------------------|-----------------------|-------------------------------------------------------------------|-----------------------------------|----------------------------------|-------------------|
| A-2 | 0.71                           | 19.6                                 | 1.2                    | 103.5                 | 9.19                                                              | 1.3                               | OK                               | Invention Steel   |
| B-2 | 0.73                           | 22.8                                 | 0.7                    | 101.6                 | 1.90                                                              | 2.9                               | OK                               | Invention Steel   |
| C-2 | 1                              | 18.4                                 | 1.0                    | 111.4                 | 6.83                                                              | 2.1                               | NG                               | Comparative Steel |
| D-2 | 0.57                           | 25.0                                 | 1.4                    | 106.5                 | 2.16                                                              | 3.3                               | OK                               | Invention Steel   |
| E-2 | 0.54                           | 13.7                                 | 0.9                    | 126.6                 | 2.57                                                              | 4.3                               | OK                               | Comparative Steel |
| F-2 | 2.23                           | 38.7                                 | 0.8                    | 98.4                  | 4.24                                                              | 12.9                              | NG                               | Comparative Steel |
| G-2 | 0.28                           | 16.2                                 | 1.1                    | 120.0                 | 1.56                                                              | 14.9                              | NG                               | Comparative Steel |
| H-2 | 0.55                           | 10.2                                 | 0.4                    | 127.3                 | 1.69                                                              | 5.2                               | OK                               | Invention Steel   |
| I-2 | 0.57                           | 18.4                                 | 0.2                    | 125.5                 | 1.89                                                              | 4.8                               | OK                               | Invention Steel   |
| J-2 | 1.95                           | 29.5                                 | 1.1                    | 104.4                 | 18.06                                                             | 0.7                               | OK                               | Invention Steel   |
| K-2 | 0.76                           | 8.8                                  | 0.7                    | 136.3                 | 0.08                                                              | 17.9                              | NG                               | Comparative Steel |
| A-3 | 0.59                           | 23.5                                 | 0.1                    | 97.9                  | 2.45                                                              | 22.6                              | NG                               | Comparative Steel |
| B-3 | 0.7                            | 8.3                                  | 0.1                    | 129.3                 | 0.16                                                              | 16.9                              | NG                               | Comparative Steel |
| C-3 | 0.48                           | 25.6                                 | 1.1                    | 104.3                 | 2.71                                                              | 2.8                               | OK                               | Invention Steel   |

(continued)

|     | Carbide size<br>size (μm) | Ferrite grain size<br>(μm) | Pearlite area<br>rate (%) | Vickers hardness<br>(HV) | No. of carbides at grain<br>boundaries/No. of carbides inside<br>grains | Ratio of maximum<br>crack length (%) | Impact resistance<br>characteristic | Remarks           |
|-----|---------------------------|----------------------------|---------------------------|--------------------------|-------------------------------------------------------------------------|--------------------------------------|-------------------------------------|-------------------|
| D-3 | 2.34                      | 16.9                       | 0.1                       | 128.6                    | 21.84                                                                   | 21.5                                 | NG                                  | Comparative Steel |
| E-3 | 0.86                      | 28.4                       | 0.6                       | 107.9                    | 3.32                                                                    | 5.0                                  | NG                                  | Comparative Steel |
| F-3 | 0.58                      | 10.3                       | 0.2                       | 124.9                    | 1.71                                                                    | 5.0                                  | OK                                  | Invention Steel   |
| G-3 | 0.72                      | 25.5                       | 1.4                       | 107.8                    | 7.56                                                                    | 1.8                                  | OK                                  | Invention Steel   |
| H-3 | 0.78                      | 22.1                       | 1.4                       | 105.2                    | 3.76                                                                    | 2.4                                  | OK                                  | Invention Steel   |
| I-3 | 0.49                      | 16.6                       | 9.5                       | 186.2                    | 2.05                                                                    | 20.5                                 | NG                                  | Comparative Steel |
| J-3 | 1.18                      | 17.9                       | 9.6                       | 189.7                    | 1.52                                                                    | 14.3                                 | NG                                  | Comparative Steel |
| K-3 | 0.74                      | 19.1                       | 0.5                       | 113.9                    | 9.88                                                                    | 1.8                                  | OK                                  | Invention Steel   |
| A-4 | 0.47                      | 11.1                       | 0.3                       | 119.0                    | 2.75                                                                    | 3.7                                  | OK                                  | Invention Steel   |
| B-4 | 0.57                      | 26.2                       | 0.8                       | 93.1                     | 2.08                                                                    | 2.5                                  | OK                                  | Comparative Steel |
| C-4 | 0.84                      | 40.2                       | 10.6                      | 195.0                    | 1.59                                                                    | 19.2                                 | NG                                  | Comparative Steel |
| D-9 | 1.26                      | 26.4                       | 8.9                       | 196.5                    | 1.23                                                                    | 14.5                                 | NG                                  | Comparative Steel |
| E-4 | 0.37                      | 11.2                       | 0.7                       | 131.7                    | 1.29                                                                    | 6.2                                  | OK                                  | Invention Steel   |
| F-4 | 0.7                       | 11.6                       | 1.4                       | 121.7                    | 13.91                                                                   | 6.2                                  | NG                                  | Comparative Steel |

(continued)

|     | Carbide size ( $\mu\text{m}$ ) | Ferrite grain size ( $\mu\text{m}$ ) | Pearlite area rate (%) | Vickers hardness (HV) | No. of carbides at grain boundaries/No. of carbides inside grains | Ratio of maximum crack length (%) | Impact resistance characteristic | Remarks           |
|-----|--------------------------------|--------------------------------------|------------------------|-----------------------|-------------------------------------------------------------------|-----------------------------------|----------------------------------|-------------------|
| G-4 | 0.48                           | 24.6                                 | 12.4                   | 211.2                 | 3.03                                                              | 18.4                              | NG                               | Comparative Steel |
| H-4 | 0.62                           | 12.6                                 | 0.3                    | 120.9                 | 5.65                                                              | 2.9                               | OK                               | Comparative Steel |
| I-4 | 0.25                           | 9.7                                  | 0.0                    | 143.3                 | 2.06                                                              | 5.7                               | OK                               | Invention Steel   |
| J-4 | 0.34                           | 13.1                                 | 14.2                   | 218.2                 | 3.13                                                              | 18.7                              | NG                               | Comparative Steel |
| K-4 | 0.38                           | 12.4                                 | 0.1                    | 125.8                 | 3.44                                                              | 3.8                               | OK                               | Invention Steel   |

**[0181]** In Comparative Steel E-3, the finish hot rolling temperature is low, the rolling load increases, and the productivity falls. In Comparative Steel D-2, the finish hot rolling temperature is high and scale flaws form at the surface of the steel plate, so when subjected to a wear resistance test after quenching and tempering, fractures and peeling occur starting from the scale flaws and the wear resistance characteristic falls. In Comparative Steel F-2, the cooling rate at the ROT (Run Out Table) is slow and a drop of productivity and formation of scale flaws are invited.

**[0182]** In Comparative Steel C-4, the cooling rate at the ROT is 100°C/sec and the outermost layer part of the steel plate is excessively cooled, so fine cracks formed at the outermost layer part. In Comparative Steel C-2, the coiling temperature is low, large amounts of bainite, martensite, and other low temperature transformed structures are formed causing embrittlement, fractures frequently form at the time of pay out from the hot rolled coil, and the productivity falls. Furthermore, in a sample taken from a cracked piece, the wear resistance characteristic is low.

**[0183]** In Comparative Steel G-2, the coiling temperature is high, bulky pearlite of lamellar spacing is formed in the hot rolled structure, the needle shaped coarse carbides become high in thermal stability, and the above carbides remain in the steel plate even after two-stage step type annealing, so the machinability is low. In Comparative Steel H-4, the heating rate in the first stage annealing of the two-stage step type annealing is slow, so the productivity is low.

**[0184]** In Comparative Steel E-3, the heating rate in the first stage annealing is fast, so the temperature difference between the inside part and inside and outside circumferential parts of the coil becomes larger, scratches and seizing occur due to the difference in thermal expansion, and, when used for evaluating and testing the wear resistance characteristic after quenching and tempering, cracks and peeling occur from the flaw parts and the wear resistance characteristic falls.

**[0185]** In Comparative Steel G-4, the holding temperature in the first stage annealing (annealing temperature) is low, the coarsening treatment of carbides at the Ac1 point or less is insufficient, and the carbides are insufficient in thermal stability, so carbides remaining at the second stage annealing are reduced and pearlite transformation in the structure after gradual cooling cannot be suppressed, so the machinability is low.

**[0186]** In Comparative Steel D-4, the holding temperature in the first stage annealing (annealing temperature) is high, austenite is formed during the annealing, and the carbides cannot be raised in stability, so pearlite is formed after annealing, the Vickers hardness exceeds 180HV, and the machinability is low. In Comparative Steel J-4, the holding time in the first stage annealing is short and the stability of carbides cannot be raised, so the machinability is low.

**[0187]** In Comparative Steel F-2, the holding time in the first stage annealing is long, the productivity is low, and further seizing flaws occur and the wear resistance characteristic is low. In Comparative Steel B-4, the heating rate in the second stage annealing in the two-stage step type annealing is slow, so the productivity is low. In Comparative Steel A-3, the heating rate at the second stage annealing is fast, so the temperature difference between the inside part and outer circumferential part of the coil become greater, scratches and seizing occur due to the large difference in heat expansion due to deformation, and the wear resistance characteristic after quenching and tempering is low.

**[0188]** In Comparative Steel K-2, the holding temperature in the second stage annealing (annealing temperature) is low, the amount of production of austenite is small, and the ratio of number of carbides at the ferrite grain boundaries cannot be increased, so the machinability is low. In Comparative Steel C-4, the holding temperature at the second stage annealing (annealing temperature) is high and dissolution of the carbides during the annealing is promoted, so it becomes difficult to form carbides at the grain boundaries after the gradual cooling and further pearlite is produced, the Vickers hardness exceeds 180HV, and the machinability is low.

**[0189]** In Comparative Steel J-3, the holding time at the second stage annealing is long and dissolution of the carbides is promoted, so the machinability is low. In Comparative Steel D-3, the cooling rate from second stage annealing to 650°C is slow, the productivity is low, coarse carbides are formed in the structure after gradual cooling, cracks are formed starting from the coarse carbides at the time of cold forging, and the cold forgeability falls. In Comparative Steel 1-3, the cooling rate from second stage annealing to 650°C is fast, the pearlite transformation occurs at the time of cooling, and the hardness increases, so the cold forgeability is low.

**[0190]** Next, to investigate the allowable contents of the other elements, continuously cast slabs (steel ingots) having the chemical compositions shown in Table 5 and Table 6 (continuation of Table 5) were heated at 1240°C for 1.8 hours, then were used for hot rolling. The finish hot rolling was ended at 890°C, the steels were cooled on a ROT by a 45°C/sec cooling rate down to 520°C and were coiled up at 510°C to produce hot rolled coils with a plate thickness of 5.2 mm.

[0195] Table 5

|    | Chemical composition (mass%) |      |      |        |        |       |        |        |        |       |       |        |       |       |
|----|------------------------------|------|------|--------|--------|-------|--------|--------|--------|-------|-------|--------|-------|-------|
|    | C                            | Si   | Mn   | P      | S      | Al    | N      | O      | Ti     | Cr    | Mo    | B      | Nb    | V     |
| AA | 0.13                         | 0.01 | 0.96 | 0.0076 | 0.0063 | 0.011 | 0.0139 | 0.0112 | 0.0043 | 0.509 | 0.869 | 0.0001 |       | 0.028 |
| AB | 0.16                         | 0.25 | 0.70 | 0.0063 | 0.0087 | 0.083 | 0.0162 | 0.0119 | 0.0028 | 0.618 | 0.680 | 0.0001 | 0.029 |       |
| AC | 0.18                         | 0.11 | 0.97 | 0.0007 | 0.0043 | 0.073 | 0.0067 | 0.0076 | 0.0095 | 1.199 | 0.402 | 0.0004 |       |       |
| AD | 0.22                         | 0.29 | 0.69 | 0.0145 | 0.0020 | 0.007 | 0.0077 | 0.0005 | 0.0015 | 1.400 | 0.807 | 0.0003 | 0.012 |       |
| AE | 0.22                         | 0.21 | 0.61 | 0.0067 | 0.0072 | 0.002 | 0.0008 | 0.0093 | 0.0072 | 1.130 | 0.422 | 0.0002 |       | 0.004 |
| AF | 0.27                         | 0.16 | 0.60 | 0.0098 | 0.0032 | 0.079 | 0.0011 | 0.0011 | 0.0042 | 1.197 | 0.010 | 0.0003 | 0.070 |       |
| AG | 0.28                         | 0.04 | 0.79 | 0.0075 | 0.0035 | 0.049 | 0.0116 | 0.0137 | 0.0028 | 0.862 | 0.802 | 0.0001 |       | 0.040 |
| AH | 0.28                         | 0.07 | 0.43 | 0.0064 | 0.0058 | 0.006 | 0.0089 | 0.0025 | 0.0036 | 1.346 | 0.510 | 0.0000 | 0.046 | 0.065 |
| AI | 0.30                         | 0.10 | 0.80 | 0.0047 | 0.0045 | 0.061 | 0.0196 | 0.0027 | 0.0057 | 0.961 | 0.002 | 0.0002 | 0.022 | 0.094 |
| AJ | 0.31                         | 0.27 | 0.60 | 0.0121 | 0.0046 | 0.077 | 0.0105 | 0.0153 | 0.0029 | 1.649 | 0.013 | 0.0001 | 0.002 | 0.084 |
| AK | 0.36                         | 0.07 | 0.60 | 0.0093 | 0.0040 | 0.028 | 0.0016 | 0.0022 | 0.0043 | 1.722 | 0.009 | 0.0004 |       |       |
| AL | 0.36                         | 0.29 | 0.89 | 0.0187 | 0.0055 | 0.048 | 0.0190 | 0.0114 | 0.0031 | 0.881 | 0.893 | 0.0004 | 0.092 |       |
| AM | 0.37                         | 0.06 | 0.84 | 0.0002 | 0.0002 | 0.072 | 0.0102 | 0.0092 | 0.0020 | 0.581 | 0.345 | 0.0001 | 0.015 | 0.037 |
| AN | 0.37                         | 0.19 | 0.45 | 0.0139 | 0.0049 | 0.033 | 0.0050 | 0.0147 | 0.0055 | 0.540 | 0.077 | 0.0001 | 0.039 | 0.012 |
| AO | 0.39                         | 0.29 | 1.00 | 0.0176 | 0.0009 | 0.068 | 0.0142 | 0.0176 | 0.0070 | 1.951 | 0.330 | 0.0002 |       |       |
| AP | 0.39                         | 0.27 | 0.82 | 0.0075 | 0.0025 | 0.025 | 0.0116 | 0.0076 | 0.0077 | 0.981 | 0.387 | 0.0002 | 0.062 |       |
| AQ | 0.39                         | 0.17 | 0.43 | 0.0194 | 0.0034 | 0.014 | 0.0037 | 0.0036 | 0.0014 | 1.480 | 0.626 | 0.0002 |       | 0.018 |

|    | Chemical composition (mass%) |       |       |       |       |       |       |       |       |       |       |       |       | Remarks         |
|----|------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----------------|
|    | Cu                           | W     | Ta    | Ni    | Sn    | Sb    | As    | Mg    | Ca    | Y     | Zr    | La    | Ce    |                 |
| AA | 0.095                        | 0.021 | 0.028 |       |       |       | 0.034 | 0.029 |       | 0.001 |       | 0.047 | 0.020 | Invention steel |
| AB | 0.082                        | 0.086 | 0.053 | 0.086 | 0.016 |       | 0.024 |       | 0.043 | 0.005 | 0.028 | 0.034 | 0.046 | Invention steel |
| AC | 0.008                        | 0.031 |       | 0.029 | 0.008 | 0.002 | 0.045 | 0.011 | 0.039 |       |       |       | 0.006 | Invention steel |
| AD | 0.019                        |       | 0.019 | 0.053 |       | 0.013 |       |       | 0.029 |       | 0.034 | 0.026 |       | Invention steel |
| AE | 0.054                        | 0.003 | 0.085 |       | 0.027 |       | 0.002 | 0.001 | 0.003 | 0.026 |       |       | 0.031 | Invention steel |
| AF | 0.038                        | 0.014 |       | 0.048 | 0.006 | 0.042 |       | 0.039 |       | 0.009 |       |       | 0.013 | Invention steel |
| AG |                              | 0.076 |       | 0.073 | 0.038 |       | 0.009 | 0.049 |       | 0.017 | 0.045 | 0.026 |       | Invention steel |
| AH | 0.076                        |       | 0.007 | 0.002 |       | 0.024 | 0.019 |       | 0.012 | 0.029 |       | 0.011 |       | Invention steel |
| AI |                              |       | 0.092 | 0.012 | 0.041 | 0.038 |       |       | 0.008 |       | 0.010 | 0.014 |       | Invention steel |
| AJ |                              |       | 0.086 | 0.080 | 0.048 | 0.027 | 0.041 | 0.021 |       |       |       | 0.030 | 0.001 | Invention steel |
| AK |                              |       |       |       |       |       |       |       | 0.003 |       |       |       |       | Invention steel |
| AL | 0.095                        | 0.042 |       | 0.078 |       |       |       | 0.005 |       |       | 0.006 | 0.046 | 0.032 | Invention steel |
| AM | 0.058                        |       | 0.062 |       |       | 0.048 | 0.011 | 0.046 | 0.006 | 0.002 | 0.021 | 0.042 |       | Invention steel |
| AN |                              | 0.067 |       | 0.093 | 0.021 | 0.006 |       | 0.044 | 0.019 |       | 0.016 | 0.001 | 0.040 | Invention steel |
| AO |                              |       |       |       |       |       |       |       |       |       |       | 0.005 |       | Invention steel |
| AP |                              |       |       |       |       |       |       |       |       |       |       |       |       | Invention steel |
| AQ |                              |       | 0.068 |       | 0.002 |       | 0.005 | 0.029 | 0.033 | 0.031 | 0.004 |       | 0.023 | Invention steel |

[0196] Table 6 (Continuation of Table 5)

|    | Chemical composition (mass%) |      |      |        |        |       |        |        |        |       |       |        |       |       |
|----|------------------------------|------|------|--------|--------|-------|--------|--------|--------|-------|-------|--------|-------|-------|
|    | C                            | Si   | Mn   | P      | S      | Al    | N      | O      | Ti     | Cr    | Mo    | B      | Nb    | V     |
| AR | 0.12                         | 0.13 | 0.95 | 0.0195 | 0.0083 | 0.06  | 0.0132 | 0.0033 | 0.0064 | 0.554 | 0.014 | 0.0005 | 0.045 | 0.006 |
| AS | 0.15                         | 0.11 | 0.52 | 0.0122 | 0.0050 | 0.008 | 0.0177 | 0.0011 | 0.0008 | 0.773 | 0.632 | 0.0001 | 0.002 | 0.038 |
| AT | 0.15                         | 0.06 | 0.70 | 0.0115 | 0.0060 | 0.036 | 0.0139 | 0.0100 | 0.0083 | 0.663 | 1.046 | 0.0005 |       | 0.001 |
| AU | 0.15                         | 0.09 | 0.57 | 0.0165 | 0.0029 | 0.048 | 0.0154 | 0.0040 | 0.0074 | 0.811 | 0.314 | 0.0002 |       |       |
| AV | 0.16                         | 0.18 | 0.54 | 0.0058 | 0.0064 | 0.086 | 0.0051 | 0.0079 | 0.0070 | 1.406 | 0.161 | 0.0002 | 0.116 |       |
| AW | 0.19                         | 0.27 | 0.67 | 0.0199 | 0.0009 | 0.083 | 0.0004 | 0.0009 | 0.0054 | 0.513 | 0.728 | 0.0002 | 0.032 |       |
| AX | 0.19                         | 0.24 | 1.00 | 0.0050 | 0.0010 | 0.084 | 0.0016 | 0.0162 | 0.0095 | 0.904 | 0.841 | 0.0004 | 0.080 | 0.077 |
| AY | 0.24                         | 0.24 | 0.53 | 0.0094 | 0.0005 | 0.018 | 0.0060 | 0.0032 | 0.0084 | 1.688 | 0.811 | 0.0003 | 0.044 |       |
| AZ | 0.24                         | 0.03 | 0.42 | 0.0050 | 0.0018 | 0.088 | 0.0076 | 0.0008 | 0.0002 | 1.216 | 0.844 | 0.0004 | 0.067 | 0.025 |
| BA | 0.28                         | 0.08 | 0.58 | 0.0005 | 0.0021 | 0.045 | 0.0094 | 0.0047 | 0.0032 | 2.037 | 0.076 | 0.0000 |       | 0.050 |
| BB | 0.30                         | 0.03 | 0.60 | 0.0044 | 0.0094 | 0.064 | 0.0015 | 0.0021 | 0.0075 | 1.285 | 0.513 | 0.0002 |       | 0.065 |
| BC | 0.31                         | 0.02 | 0.57 | 0.0130 | 0.0074 | 0.041 | 0.0050 | 0.0157 | 0.0001 | 1.379 | 0.004 | 0.0001 | 0.032 | 0.051 |
| BD | 0.33                         | 0.30 | 0.84 | 0.0140 | 0.0095 | 0.057 | 0.0085 | 0.0169 | 0.0030 | 1.648 | 0.182 | 0.0000 |       |       |
| BE | 0.34                         | 0.29 | 0.58 | 0.0004 | 0.0087 | 0.072 | 0.0011 | 0.0092 | 0.0019 | 1.094 | 0.007 | 0.0003 | 0.091 | 0.079 |
| BF | 0.34                         | 0.29 | 0.94 | 0.0149 | 0.0024 | 0.022 | 0.0167 | 0.0036 | 0.0050 | 1.561 | 0.856 | 0.0003 |       | 0.097 |
| BG | 0.36                         | 0.36 | 0.60 | 0.0157 | 0.0088 | 0.086 | 0.0198 | 0.0064 | 0.0012 | 0.934 | 0.268 | 0.0001 |       |       |
| BH | 0.36                         | 0.28 | 0.63 | 0.0099 | 0.0091 | 0.032 | 0.0098 | 0.0051 | 0.0029 | 1.624 | 0.011 | 0.0000 | 0.047 | 0.044 |
| BI | 0.37                         | 0.14 | 1.17 | 0.0014 | 0.0048 | 0.094 | 0.0151 | 0.0113 | 0.0003 | 1.210 | 0.003 | 0.0000 | 0.085 |       |
| BJ | 0.39                         | 0.19 | 0.95 | 0.0071 | 0.0012 | 0.094 | 0.0014 | 0.0186 | 0.0082 | 1.317 | 0.849 | 0.0002 | 0.051 | 0.118 |
| BK | 0.45                         | 0.17 | 0.61 | 0.0115 | 0.0055 | 0.054 | 0.0024 | 0.0167 | 0.0086 | 0.688 | 0.118 | 0.0000 | 0.043 |       |

|    | Chemical composition (mass%) |       |       |       |       |       |       |       |       |       |       |       |       | Remarks           |
|----|------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------------------|
|    | Cu                           | W     | Ta    | Ni    | Sn    | Sb    | As    | Mg    | Ca    | Y     | Zr    | La    | Ce    |                   |
| AR |                              | 0.075 |       | 0.084 |       |       |       | 0.024 | 0.027 |       | 0.049 | 0.052 |       | Comparative steel |
| AS | 0.025                        | 0.055 | 0.041 |       | 0.003 |       | 0.058 | 0.001 | 0.040 | 0.044 |       | 0.013 | 0.026 | Comparative steel |
| AT | 0.012                        | 0.048 | 0.011 | 0.011 | 0.031 |       |       | 0.026 |       |       | 0.029 |       |       | Comparative steel |
| AU | 0.098                        |       | 0.095 |       | 0.047 |       | 0.008 |       | 0.037 |       | 0.053 |       | 0.011 | Comparative steel |
| AV |                              |       |       | 0.078 | 0.005 | 0.048 | 0.027 | 0.035 |       |       |       | 0.040 | 0.006 | Comparative steel |
| AW | 0.131                        |       | 0.021 |       |       | 0.036 | 0.012 | 0.025 | 0.004 | 0.036 | 0.040 | 0.015 | 0.006 | Comparative steel |
| AX | 0.087                        | 0.045 |       |       | 0.011 | 0.040 | 0.014 | 0.043 | 0.058 | 0.020 | 0.041 | 0.046 |       | Comparative steel |
| AY |                              |       | 0.014 | 0.095 | 0.025 |       | 0.005 | 0.052 | 0.027 | 0.040 |       | 0.027 | 0.027 | Comparative steel |
| AZ | 0.097                        |       | 0.073 | 0.106 | 0.009 | 0.044 | 0.017 | 0.020 | 0.022 | 0.025 | 0.025 |       | 0.014 | Comparative steel |
| BA |                              | 0.031 | 0.036 |       | 0.020 | 0.008 | 0.027 |       | 0.012 | 0.050 | 0.026 | 0.017 |       | Comparative steel |
| BB | 0.051                        | 0.091 | 0.072 | 0.005 |       | 0.055 |       |       |       | 0.019 | 0.012 |       | 0.002 | Comparative steel |
| BC | 0.034                        | 0.003 | 0.105 | 0.064 | 0.005 | 0.005 |       |       |       | 0.029 | 0.028 | 0.049 |       | Comparative steel |
| BD |                              |       |       |       | 0.059 |       |       |       |       |       |       |       |       | Comparative steel |
| BE | 0.099                        | 0.019 |       |       |       |       | 0.049 | 0.038 | 0.043 | 0.062 | 0.028 | 0.022 | 0.032 | Comparative steel |
| BF | 0.023                        | 0.049 |       | 0.079 |       | 0.049 |       | 0.001 | 0.001 |       |       | 0.002 | 0.051 | Comparative steel |
| BG | 0.070                        |       | 0.005 |       | 0.040 |       | 0.047 | 0.016 | 0.023 |       | 0.032 | 0.002 |       | Comparative steel |
| BH |                              | 0.107 | 0.014 | 0.068 | 0.045 |       | 0.003 | 0.014 |       | 0.018 |       |       |       | Comparative steel |
| BI |                              | 0.008 | 0.028 |       | 0.017 | 0.029 | 0.006 | 0.009 | 0.027 | 0.037 | 0.038 |       |       | Comparative steel |
| BJ | 0.077                        | 0.096 | 0.076 | 0.012 | 0.046 | 0.036 | 0.047 |       | 0.011 | 0.022 |       | 0.043 | 0.011 | Comparative steel |
| BK |                              | 0.083 |       | 0.048 | 0.016 | 0.025 |       | 0.039 |       |       |       | 0.004 | 0.046 | Comparative steel |

[0191] The hot rolled coils were pickled, the hot rolled coils were loaded into a box-type annealing furnace, the atmosphere was controlled to 95% hydrogen-5% nitrogen, then the coils were heated from room temperature up to 705°C by a heating rate of 100°C/hour, were held at 705°C for 36 hours to make the temperature distribution inside the coils

uniform, then were heated by a 5°C/hour heating rate up to 760°C, and, furthermore, were held at 760°C for 10 hours, then were cooled down to 650°C by a 10°C/hour cooling rate, then were furnace cooled down to room temperature to prepare samples for evaluation of the characteristics.

**[0192]** Note that, the structures of the samples were observed by the above-mentioned method while the crack lengths present in the samples after cold forging were measured by the above-mentioned method.

**[0193]** Table 7 shows the results of measurement and results of evaluation of the carbide size, pearlite area ratio, ferrite grain size, Vickers hardness, ratio of the number of carbides at the ferrite grain boundaries to number of carbides in the ferrite grains, ratio of maximum crack length to plate thickness at the vertical wall parts, and impact resistance characteristics in the prepared samples.

Table 7

|      | Carbide size (μm) | Ferrite grain size (μm) | Pearlite area rate (%) | Vickers hardness (HV) | No. of carbides at grain boundaries/ No. of carbides inside grains | Ratio of maximum crack length (%) | Impact resistance characteristic | Remarks         |
|------|-------------------|-------------------------|------------------------|-----------------------|--------------------------------------------------------------------|-----------------------------------|----------------------------------|-----------------|
| AA-1 | 1.14              | 23.5                    | 1.2                    | 103.1                 | 9.53                                                               | 0.8                               | OK                               | Invention steel |
| AB-1 | 1.04              | 20                      | 0.7                    | 119.7                 | 7.19                                                               | 1.5                               | OK                               | Invention steel |
| AC-1 | 0.99              | 17.5                    | 0.7                    | 117.2                 | 7.03                                                               | 1.4                               | OK                               | Invention steel |
| AD-1 | 0.89              | 16.4                    | 0.3                    | 127.0                 | 5.25                                                               | 2.0                               | OK                               | Invention steel |
| AE-1 | 0.94              | 17.8                    | 0.7                    | 119.5                 | 5.81                                                               | 1.7                               | OK                               | Invention steel |
| AF-1 | 0.88              | 16.8                    | 1.4                    | 121.6                 | 4.71                                                               | 1.9                               | OK                               | Invention steel |
| AG-1 | 1.02              | 17.6                    | 0.0                    | 114.8                 | 7.35                                                               | 1.3                               | OK                               | Invention steel |
| AH-1 | 0.86              | 19.1                    | 0.7                    | 111.6                 | 4.56                                                               | 1.6                               | OK                               | Invention steel |
| AI-1 | 1                 | 17.4                    | 0.0                    | 119.7                 | 6.75                                                               | 1.6                               | OK                               | Invention steel |
| AJ-1 | 0.79              | 15.3                    | 0.8                    | 132.5                 | 3.60                                                               | 2.5                               | OK                               | Invention steel |
| AK-1 | 0.79              | 15.2                    | 1.4                    | 122.3                 | 3.66                                                               | 2.1                               | OK                               | Invention steel |
| AL-1 | 1.03              | 16.1                    | 0.8                    | 136.0                 | 7.59                                                               | 2.0                               | OK                               | Invention steel |
| AM-1 | 1.06              | 17.6                    | 0.3                    | 120.6                 | 7.63                                                               | 1.5                               | OK                               | Invention steel |
| AN-1 | 0.97              | 19.1                    | 0.1                    | 124.2                 | 5.46                                                               | 1.9                               | OK                               | Invention steel |
| AO-1 | 0.83              | 13.4                    | 1.0                    | 142.6                 | 4.61                                                               | 2.6                               | OK                               | Invention steel |
| AP-1 | 0.98              | 16                      | 0.2                    | 135.4                 | 6.32                                                               | 2.2                               | OK                               | Invention steel |

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(continued)

|    |      |                   |                         |                        |                       |                                                                    |                                   |                                  |                   |
|----|------|-------------------|-------------------------|------------------------|-----------------------|--------------------------------------------------------------------|-----------------------------------|----------------------------------|-------------------|
| 5  |      | Carbide size (μm) | Ferrite grain size (μm) | Pearlite area rate (%) | Vickers hardness (HV) | No. of carbides at grain boundaries/ No. of carbides inside grains | Ratio of maximum crack length (%) | Impact resistance characteristic | Remarks           |
| 10 | AQ-1 | 0.81              | 17.3                    | 1.1                    | 126.3                 | 3.88                                                               | 2.2                               | OK                               | Invention steel   |
| 15 | AR-1 | 1.1               | 22.8                    | 0.7                    | 111.3                 | 0.15                                                               | <u>14.9</u>                       | <u>NG</u>                        | Comparative steel |
| 20 | AS-1 | 0.99              | 22                      | 1.0                    | 105.6                 | <u>0.28</u>                                                        | <u>14.0</u>                       | <u>NG</u>                        | Comparative steel |
| 25 | AT-1 | 1.07              | 21.3                    | 7.8                    | <u>188.0</u>          | 0.19                                                               | 22.6                              | <u>NG</u>                        | Comparative steel |
| 30 | AU-1 | 0.98              | 21.2                    | 1.3                    | 106.4                 | 6.89                                                               | <u>21.9</u>                       | <u>NG</u>                        | Comparative steel |
| 35 | AV-1 | 0.83              | 18.1                    | 13.1                   | <u>243.1</u>          | <u>0.44</u>                                                        | <u>26.4</u>                       | <u>NG</u>                        | Comparative steel |
| 40 | AW-1 | 0.94              | 19.2                    | 0.6                    | 122.5                 | 0.04                                                               | 16.5                              | NG                               | Comparative steel |
| 45 | AX-1 | 1.06              | 17.5                    | 0.4                    | 126.0                 | 10.11                                                              | <u>21.4</u>                       | <u>NG</u>                        | Comparative steel |
| 50 | AY-1 | 1.06              | 16.7                    | 1.5                    | 123.4                 | 4.01                                                               | 14.8                              | NG                               | Comparative steel |
| 55 | AZ-1 | 0.81              | 19.8                    | 0.4                    | 107.8                 | <u>0.89</u>                                                        | <u>12.4</u>                       | <u>NG</u>                        | Comparative steel |
|    | BA-1 | 0.87              | 15.2                    | 11.4                   | <u>234.4</u>          | 0.25                                                               | 26.3                              | NG                               | Comparative steel |
|    | BB-1 | 0.73              | 16.7                    | 1.0                    | 115.2                 | <u>0.11</u>                                                        | 15.5                              | <u>NG</u>                        | Comparative steel |
|    | BC-1 | 0.9               | 16.8                    | 9.8                    | <u>212.6</u>          | <u>0.94</u>                                                        | 21.2                              | <u>NG</u>                        | Comparative steel |
|    | BD-1 | 0.88              | 14.1                    | 1.2                    | 138.2                 | 4.53                                                               | <u>13.4</u>                       | <u>NG</u>                        | Comparative steel |
|    | BE-1 | 0.9               | 16.4                    | 0.6                    | 133.4                 | 4.83                                                               | <u>11.2</u>                       | <u>NG</u>                        | Comparative steel |
|    | BF-1 | 0.85              | 14.6                    | 1.2                    | 137.2                 | <u>0.73</u>                                                        | <u>16.2</u>                       | <u>NG</u>                        | Comparative steel |
|    | BG-1 | 0.9               | 16.5                    | 0.7                    | 138.8                 | 4.97                                                               | 13.8                              | <u>NG</u>                        | Comparative steel |
|    | BH-1 | 0.93              | 14.9                    | 10.6                   | <u>228.7</u>          | <u>0.85</u>                                                        | <u>23.4</u>                       | <u>NG</u>                        | Comparative steel |
|    | BI-1 | 0.91              | 16.6                    | 0.3                    | 128.4                 | 7.24                                                               | 3.0                               | <u>NG</u>                        | Comparative steel |
|    | BJ-1 | 0.82              | 14.5                    | 11.9                   | <u>240.6</u>          | <u>0.24</u>                                                        | <u>26.8</u>                       | <u>NG</u>                        | Comparative steel |

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(continued)

|      | Carbide size (μm) | Ferrite grain size (μm) | Pearlite area rate (%) | Vickers hardness (HV) | No. of carbides at grain boundaries/ No. of carbides inside grains | Ratio of maximum crack length (%) | Impact resistance characteristic | Remarks           |
|------|-------------------|-------------------------|------------------------|-----------------------|--------------------------------------------------------------------|-----------------------------------|----------------------------------|-------------------|
| BK-1 | 1.01              | 16.6                    | 0.8                    | 131.5                 | 22.08                                                              | 1.1                               | <u>NG</u>                        | Comparative steel |

**[0194]** As shown in Table 7, in each of Invention Steels AA-1, AB-1, AC-1, AD-1, AE-1, AF-1, AG-1, AH-1, AI-1, AJ-1, AK-1, AL-1, AM-1, AN-1, AO-1, AP-1, and AQ-1, the ratio of the number of carbides at the ferrite grain boundaries to the number of carbides in the ferrite grains exceeds 1, the Vickers hardness is 100HV to 180HV, and the cold forgeability and impact resistance characteristic after carburizing, quenching, and tempering are excellent.

**[0195]** As opposed to this, in each of Comparative Steels AR-1, AS-1, AW-1, AZ-1, BB-1, and BF-1, La, As, Cu, Ni, Sb, and Ce are excessively contained and the amount of segregation at the  $\gamma/\alpha$  interface becomes greater at the time of second stage annealing, so formation of carbides at the grain boundaries is suppressed. In Comparative Steel BG-1, Si is excessively contained and the ductility of the ferrite is low, so the cold forgeability is low.

**[0196]** In each of Comparative Steels AT-1, AV-1, BA-1, BC-1, BH-1, and BJ-1, Mo, Nb, Cr, Ta, W, and V are respectively excessively contained, so carbides finely disperse inside the ferrite grains and the hardness exceeds 180HV. In Comparative Steel BF-1, Mn is excessively contained, so the impact resistance characteristic after carburizing, quenching, and tempering is remarkably low.

**[0197]** In each of Comparative Steels AU-1, AX-1, AY-1, and BE-1, Zr, Ca, Mg, and Y are respectively excessively contained, coarse oxides or nonmetallic inclusions are formed in the steel, cracks form starting from the coarse oxides or coarse nonmetallic inclusions at the time of cold forging, and the cold forgeability falls. In Comparative Steel BD-1, Sn is excessively contained, the ferrite becomes brittle, and the cold forgeability is low. In Comparative Steel BK-1, C is excessively contained, so coarse carbides form at the inside of the increased thickness part of the steel, coarse carbides remain even after carburizing and quenching, and the impact resistance characteristic also falls.

**[0198]** Next, to investigate the effects of the manufacturing conditions, slabs having the chemical compositions of AA, AB, AC, AD, AE, AF, AG, AH, AI, AJ, AK, AL, AM, AN, AO, AP, and AQ shown in Table 5 were hot rolled and annealed under the conditions shown in Table 8 to fabricate annealed samples of hot rolled plates of thicknesses of 5.2 mm.

Table 8

|      | Hot rolling conditions |                      |                               |                           |                    | Annealing conditions   |                    |                      |                        |                    |                      | Remarks    |             |
|------|------------------------|----------------------|-------------------------------|---------------------------|--------------------|------------------------|--------------------|----------------------|------------------------|--------------------|----------------------|------------|-------------|
|      | Heating temp. (°C)     | Soaking time (hours) | Finish hot rolling temp. (°C) | ROT cooling rate (°C/sec) | Coiling temp. (°C) | 1st stage              |                    |                      | 2nd stage              |                    |                      |            |             |
|      |                        |                      |                               |                           |                    | Heating rate (°C/hour) | Holding temp. (°C) | Holding time (hours) | Heating rate (°C/hour) | Holding temp. (°C) | Holding time (hours) |            |             |
| AA-2 | 1143                   | 0.4                  | 836.3                         | 11                        | 403.5              | 124                    | 644                | 31.9                 | 36.2                   | 774                | 14.2                 | 47.5       | Comp. steel |
| AB-2 | 1199                   | 4.5                  | 939.4                         | 17                        | 435.8              | 123.4                  | 692.3              | 38.9                 | 52.5                   | 766.7              | 34.7                 | 35.3       | Inv. steel  |
| AC-2 | 1043                   | 4.2                  | 641                           | 61                        | 415.4              | 75.8                   | 703.9              | 50.4                 | 24.2                   | 741.7              | 15.1                 | 88.1       | Comp. steel |
| AD-2 | 1272                   | 0.8                  | 812.8                         | 65                        | 467.4              | 96.7                   | 692.7              | 59.9                 | 39.6                   | 796                | 7.3                  | 60.5       | Comp. steel |
| AE-2 | 1164                   | 0.5                  | 902.3                         | 53                        | 554                | 131.8                  | 670.2              | 15.7                 | 78.3                   | 734.5              | 49.8                 | 66.4       | Inv. steel  |
| AF-2 | 1238                   | 4.5                  | 832                           | 42                        | 435.3              | 40.5                   | 671.4              | 2.7                  | 29.3                   | 757.4              | 11.8                 | 6.1        | Comp. steel |
| AG-2 | 1226                   | 3.4                  | 830.5                         | 14                        | 503.9              | 171                    | 688.5              | 28.1                 | 14.6                   | 747                | 10.8                 | 51         | Comp. steel |
| AH-2 | 1050                   | 1.4                  | 833                           | 48                        | 558.2              | 102                    | 706.7              | 22.2                 | 26.9                   | 744.5              | 49.7                 | 80.7       | Inv. steel  |
| AI-2 | 1067                   | 2.8                  | 690.7                         | 26                        | 452                | 45.7                   | 662.2              | 31.5                 | 53.6                   | 737.7              | 10.2                 | 29.6       | Inv. steel  |
| AJ-2 | 1008                   | 1.4                  | 850.8                         | 53                        |                    | 70.8                   | 693.9              | 29.9                 | 4.9                    | 787.8              | 41.6                 | 83.3       | Inv. steel  |
| AK-2 | 1166                   | 4.8                  | 729.7                         | 23                        | 510                | 43.9                   | 667.2              | 13.6                 | 32                     | 753                | 7.5                  | 40.4       | Inv. steel  |
| AL-2 | 1150                   | 1.7                  | 802.3                         | 60                        | 516.2              | 95.6                   | 660.4              | 47.1                 | 21.8                   | 742.7              | 30                   | 36.1       | Inv. steel  |
| AM-2 | 1083                   | 1.4                  | 779.6                         | 66                        |                    | 86.2                   | 685.7              | 25.5                 | 22.8                   | 754                | 28.5                 | 15.4       | Inv. steel  |
| AN-2 | 1084                   | 1.1                  | 799.6                         | 96                        | 552.8              | 74.1                   | 712                | 52.5                 | 53.4                   | 739                | 43.4                 | 17.4       | Inv. steel  |
| AO-2 | 1194                   | 2.2                  | 710.1                         | 16                        | 592.8              | 42.5                   | 689.2              | 50.7                 | 67.4                   | 748                | 27.1                 | 86.6       | Inv. steel  |
| AP-2 | 1101                   | 2.5                  | 800.4                         | 61                        | 980.4              | 119                    | 702                | 12.1                 | 71.1                   | 781.4              | 27.7                 | <u>123</u> | Comp. steel |
| AQ-2 | -                      | -                    | 842.1                         | 24                        | 403.5              | 43.2                   | 693.2              | 29.7                 | 23.7                   | 773.9              | 31.1                 | 48.3       | Inv. steel  |

(continued)

|      | Hot rolling conditions |                      |                               |                           |                    | Annealing conditions   |                    |                      |                        |                    |                      | Remarks |             |
|------|------------------------|----------------------|-------------------------------|---------------------------|--------------------|------------------------|--------------------|----------------------|------------------------|--------------------|----------------------|---------|-------------|
|      | Heating temp. (°C)     | Soaking time (hours) | Finish hot rolling temp. (°C) | ROT cooling rate (°C/sec) | Coiling temp. (°C) | 1st stage              |                    |                      | 2nd stage              |                    |                      |         |             |
|      |                        |                      |                               |                           |                    | Heating rate (°C/hour) | Holding temp. (°C) | Holding time (hours) | Heating rate (°C/hour) | Holding temp. (°C) | Holding time (hours) |         |             |
| AA-3 | 1173                   | 3.4                  | 758.8                         | 45                        | 521.1              | 81.2                   | 686.8              | 18.4                 | 8.6                    | 751                | 21.3                 | 27      | Inv. steel  |
| AB-3 | 1023                   | 2.8                  | 834.7                         | 10                        | 500.4              | 114                    | 677.3              | 27.6                 | 59.8                   | 745.4              | 21.5                 | 64.7    | Inv. steel  |
| AC-3 | 1296                   | 0.6                  | 725.4                         | 87                        | 416.2              | 142.7                  | 682.2              | 58.8                 | 40.3                   | 740.1              | 10.7                 | 4.9     | Inv. steel  |
| AD-3 | 1143                   | 3.9                  | 946.1                         | 91                        | 588.6              | 36.6                   | 677.3              | 53.1                 | 8.8                    | 737.3              | 6.9                  | 72      | Inv. steel  |
| AE-3 | 1110                   | 0.6                  | 879.7                         | 44                        | 454.5              | 106.6                  | 678.1              | 31.5                 | 57.6                   | 770                | 18.1                 | 42.7    | Inv. steel  |
| AF-3 | 1054                   | 5.9                  | 684.6                         | 97                        | 526.2              | 49.1                   | 693.9              | 32.5                 | 44.5                   | 777.1              | 28.3                 | 40.4    | Inv. steel  |
| AG-3 | 1163                   | 4.2                  | 773                           | 63                        | 501.3              | 52.9                   | 701.8              | 9.8                  | 18.2                   | 751.3              | 44.4                 | 43.7    | Inv. steel  |
| AH-3 | 1122                   | 0.5                  | 884.9                         | 36                        | 613                | 84.2                   | 686.6              | 58.5                 | 2.9                    | 731.3              | 33.9                 | 39      | Comp. steel |
| AI-3 | 1245                   | 7.0                  | 797.5                         | 44                        | 433.1              | 136.2                  | 698.7              | 54.9                 | 91                     | 778                | 48.4                 | 60.6    | Comp. steel |
| AJ-3 | 1281                   | 4.8                  | 895.7                         | 100                       | 562.9              | 127                    | 673.4              | 18.9                 | 13.2                   | 748                | 28.7                 | 78.6    | Inv. steel  |
| AK-3 | 1164                   | 5.0                  | 910.4                         | 86                        | 486.1              | 123.9                  | 653.8              | 56.4                 | 4.9                    | 758.9              | 2.1                  | 41.5    | Comp. steel |
| AL-3 | 1212                   | 0.8                  | 691                           | 87                        | 486.5              | 61.8                   | 693.4              | 30.6                 | 15.3                   | 709                | 23.5                 | 85.9    | Comp. steel |
| AM-3 | 1098                   | 4.5                  | 798.7                         | 44                        | 543.5              | 130.7                  | 726                | 4.9                  | 46                     | 770.2              | 43.9                 | 19.4    | Comp. steel |
| AN-3 | 1022                   | 7.0                  | 879.7                         | 48                        | 391                | 146.2                  | 657                | 13.7                 | 10.9                   | 765.1              | 32.7                 | 89.9    | Comp. steel |
| AO-3 | 1094                   | 3.9                  | 725.5                         | 67                        | 488.4              | 137.2                  | 671.4              | 42.5                 | 71.1                   | 778.9              | 19.5                 | 40.3    | Inv. steel  |
| AP-3 | 1083                   | 1.1                  | 919.3                         | 99                        | 573.9              | 42.3                   | 715.3              | 25.6                 | 25.8                   | 730.3              | 14.9                 | 97.7    | Inv. steel  |

(continued)

|      | Hot rolling conditions |                      |                               |                            |                    | Annealing conditions    |                    |                      |                         |                    |                      | Remarks |             |
|------|------------------------|----------------------|-------------------------------|----------------------------|--------------------|-------------------------|--------------------|----------------------|-------------------------|--------------------|----------------------|---------|-------------|
|      | Heating temp. (°C)     | Soaking time (hours) | Finish hot rolling temp. (°C) | ROT cooling rate (°C/ sec) | Coiling temp. (°C) | 1st stage               |                    |                      | 2nd stage               |                    |                      |         |             |
|      |                        |                      |                               |                            |                    | Heating rate (°C/ hour) | Holding temp. (°C) | Holding time (hours) | Heating rate (°C/ hour) | Holding temp. (°C) | Holding time (hours) |         |             |
| AQ-3 | 1096                   | 3.1                  | 743.6                         | 22                         | 527.4              | 113.3                   | 652.7              | 46.3                 | 13.6                    | 751.3              | 14.3                 | 0.3     | Comp. steel |
| AA-4 | -                      | -                    | 834.5                         | 36                         | 533.2              | 83.3                    | 698                | 47.6                 | 29.4                    | 764.4              | 22.3                 | 86.5    | Inv. steel  |
| AB-4 | 1300                   | 5.3                  | 719.6                         | 27                         | 491.8              | 32                      | 659.5              | 32.9                 | 69                      | 784.1              | 6.1                  | 50.4    | Inv. steel  |
| AC-4 | 1049                   | 0.6                  | 898.5                         | 63                         | 540.1              | 36.5                    | 717.1              | 39.5                 | 64.7                    | 782.3              | 5.9                  | 14.8    | Inv. steel  |
| AD-4 | 1264                   | 6.4                  | 872.2                         | 100                        | 530.3              | 104.7                   | 707.5              | 6.8                  | 47.5                    | 747.7              | 19.4                 | 12.5    | Inv. steel  |
| AE-4 | 1160                   | 5.0                  | 808.3                         | 55                         | 556.7              | 67.8                    | 655.3              | 38.3                 | 72.6                    | 735                | 28.4                 | 45.8    | Inv. steel  |
| AF04 | 1011                   | 3.4                  | 885.6                         | 60                         | 402.3              | 24                      | 662.5              | 45.8                 | 17.2                    | 742.7              | 36.9                 | 55.7    | Comp. steel |
| AG-4 | 1044                   | 0.4                  | 716.6                         | 98                         | 496.5              | 55.1                    | 684.3              | 23.5                 | 67.4                    | 756.7              | 41.2                 | 22.4    | Inv. steel  |
| AH-4 | 1286                   | 5.0                  | 696.9                         | 92                         | 444.3              | 65.3                    | 656.9              | 44.4                 | 46.8                    | 750.3              | 28.5                 | 21.8    | Inv. steel  |
| AI-4 | 1054                   | 1.7                  | 754.6                         | 90                         | 452.1              | 55.4                    | 705.2              | 51.8                 | 14.6                    | 775.6              | 39.6                 | 68      | Inv. steel  |
| A-4  | 1233                   | 5.9                  | 772.2                         | 22                         | 536.2              | 63.2                    | 675.9              | 26.3                 | 3                       | 756.9              | 66                   | 23.7    | Comp. steel |
| AK-4 | 1010                   | 5.6                  | 940.5                         | 47                         | 554.4              | 122.4                   | 689.8              | 30.8                 | 27.1                    | 759.8              | 27                   | 59      | Inv. steel  |
| AL-4 | 1199                   | 6.2                  | 846.4                         | 92                         | 557.1              | 99.3                    | 706.2              | 25.6                 | 64                      | 753.3              | 20.6                 | 99.2    | Inv. steel  |
| AM-4 | 1239                   | 3.6                  | 750.5                         | 38                         | 500.7              | 150                     | 688.9              | 31.9                 | 44.5                    | 780.5              | 49.5                 | 34.3    | Inv. steel  |
| AN-4 | 1256                   | 5.6                  | 956                           | 74                         | 498                | 149.2                   | 690.8              | 8                    | 74.8                    | 744.3              | 38.8                 | 76.6    | Comp. steel |
| AO-4 | 1241                   | 6.7                  | 750.8                         | 56                         | 454                | 118.1                   | 657.9              | 61.5                 | 47.4                    | 747.4              | 43.6                 | 20      | Comp. steel |
| AP-4 | 1043                   | 4.8                  | 800.3                         | 78                         | 417.4              | 31.9                    | 707                | 7.8                  | 0.5                     | 766.1              | 8.1                  | 2.7     | Comp. steel |

(continued)

|      | Hot rolling conditions |                      |                               |                            |                    | Annealing conditions    |                    |                      |                    |                         |                      |                                      | Remarks    |
|------|------------------------|----------------------|-------------------------------|----------------------------|--------------------|-------------------------|--------------------|----------------------|--------------------|-------------------------|----------------------|--------------------------------------|------------|
|      | Heating temp. (°C)     | Soaking time (hours) | Finish hot rolling temp. (°C) | ROT cooling rate (°C/ sec) | Coiling temp. (°C) | 1st stage               |                    |                      | 2nd stage          |                         |                      | Cooling rate down to 650°C (°C/hour) |            |
|      |                        |                      |                               |                            |                    | Heating rate (°C/ hour) | Holding temp. (°C) | Holding time (hours) | Holding temp. (°C) | Heating rate (°C/ hour) | Holding time (hours) |                                      |            |
| AQ-9 | 1032                   | 2.2                  | 793.4                         | 43                         | 559.4              | 64.8                    | 718                | 13                   | 51.2               | 748.4                   | 17.1                 | 15.9                                 | Inv. steel |

**[0199]** Table 9 shows the results of measurement and results of evaluation of the carbide size, pearlite area ratio, ferrite grain size, Vickers hardness, ratio of the number of carbides at the ferrite grain boundaries to number of carbides in the ferrite grains, ratio of maximum crack length to plate thickness at the vertical wall parts, and impact resistance characteristic in the prepared samples.

Table 9

|      | Carbide size ( $\mu\text{m}$ ) | Ferrite grain size ( $\mu\text{m}$ ) | Pearlite area rate (%) | Vickers hardness (HV) | No. of carbides at grain boundaries/<br>No. of carbides inside grains | Ratio of maximum crack length (%) | Impact resistance characteristic | Remarks           |
|------|--------------------------------|--------------------------------------|------------------------|-----------------------|-----------------------------------------------------------------------|-----------------------------------|----------------------------------|-------------------|
| AA-2 | 0.78                           | 23.8                                 | 9.1                    | 195.2                 | 13.70                                                                 | 15.6                              | NG                               | Comparative Steel |
| AB-2 | 0.78                           | 26.2                                 | 1.2                    | 108.9                 | 3.56                                                                  | 1.6                               | OK                               | Invention Steel   |
| AC-2 | 0.74                           | 13.0                                 | 0.0                    | 120.8                 | 1.35                                                                  | 3.2                               | OK                               | Comparative Steel |
| AD-2 | 0.75                           | 23.2                                 | 10.3                   | 214.7                 | 2.81                                                                  | 18.8                              | NG                               | Comparative Steel |
| AE-2 | 0.17                           | 14.7                                 | 0.1                    | 121.4                 | 1.26                                                                  | 5.6                               | OK                               | Invention Steel   |
| AF-2 | 0.97                           | 18.0                                 | 13.1                   | 217.2                 | 8.98                                                                  | 13.5                              | NG                               | Comparative Steel |
| AG-2 | 0.56                           | 11.5                                 | 0.4                    | 122.1                 | 3.35                                                                  | 2.2                               | NG                               | Comparative Steel |
| AH-2 | 0.46                           | 21.7                                 | 1.4                    | 105.3                 | 1.20                                                                  | 4.7                               | OK                               | Invention Steel   |
| AI-2 | 0.49                           | 9.4                                  | 0.2                    | 132.6                 | 6.21                                                                  | 2.0                               | OK                               | Invention Steel   |
| AJ-2 | 0.44                           | 20.8                                 | 1.0                    | 125.0                 | 1.92                                                                  | 4.7                               | OK                               | Invention Steel   |
| AK-2 | 0.37                           | 10.7                                 | 1.2                    | 127.5                 | 5.48                                                                  | 2.0                               | OK                               | Invention Steel   |
| AL-2 | 0.52                           | 12.1                                 | 0.9                    | 137.5                 | 5.69                                                                  | 2.3                               | OK                               | Invention Steel   |
| AM-2 | 0.81                           | 16.5                                 | 1.4                    | 116.4                 | 9.20                                                                  | 1.3                               | OK                               | Invention Steel   |
| AN-2 | 0.75                           | 20.9                                 | 0.9                    | 117.0                 | 1.35                                                                  | 5.1                               | OK                               | Invention Steel   |
| AO-2 | 0.43                           | 10.0                                 | 1.5                    | 144.9                 | 1.34                                                                  | 6.9                               | OK                               | Invention Steel   |
| AP-2 | 0.48                           | 16.4                                 | 14.2                   | 228.1                 | 2.16                                                                  | 19.9                              | NG                               | Comparative Steel |
| AQ-2 | 0.65                           | 26.7                                 | 0.9                    | 113.1                 | 2.74                                                                  | 2.0                               | OK                               | Invention Steel   |
| AA-3 | 0.73                           | 17.0                                 | 0.1                    | 106.1                 | 9.74                                                                  | 0.8                               | OK                               | Invention Steel   |

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(continued)

|    |      |                   |                         |                        |                       |                                                                       |                                   |                                  |                   |
|----|------|-------------------|-------------------------|------------------------|-----------------------|-----------------------------------------------------------------------|-----------------------------------|----------------------------------|-------------------|
| 5  |      | Carbide size (μm) | Ferrite grain size (μm) | Pearlite area rate (%) | Vickers hardness (HV) | No. of carbides at grain boundaries/<br>No. of carbides inside grains | Ratio of maximum crack length (%) | Impact resistance characteristic | Remarks           |
| 10 | AB-3 | 0.48              | 14.3                    | 0.7                    | 124.1                 | 3.28                                                                  | 2.3                               | OK                               | Invention Steel   |
|    | AC-3 | 1.02              | 12.3                    | 1.2                    | 125.9                 | 11.41                                                                 | 1.4                               | OK                               | Invention Steel   |
| 15 | AD-3 | 0.36              | 7.5                     | 1.3                    | 147.6                 | 1.18                                                                  | 7.7                               | OK                               | Invention Steel   |
|    | AE-3 | 0.65              | 21.5                    | 0.8                    | 111.5                 | 5.36                                                                  | 1.4                               | OK                               | Invention Steel   |
| 20 | AF-3 | 0.63              | 23.3                    | 1.5                    | 110.3                 | 2.88                                                                  | 1.9                               | OK                               | Invention Steel   |
|    | AG-3 | 0.57              | 17.0                    | 0.1                    | 110.2                 | 3.90                                                                  | 1.6                               | OK                               | Invention Steel   |
| 25 | AH-3 | 0.79              | 14.5                    | 1.5                    | 115.4                 | 4.28                                                                  | 13.1                              | NG                               | Comparative Steel |
|    | AI-3 | 0.75              | 25.1                    | 0.6                    | 105.8                 | 1.93                                                                  | 2.1                               | NG                               | Comparative Steel |
| 30 | AJ-3 | 0.21              | 14.8                    | 1.5                    | 129.8                 | 1.27                                                                  | 6.2                               | OK                               | Invention Steel   |
|    | AK-3 | 0.46              | 9.0                     | 0.8                    | 133.6                 | 0.66                                                                  | 10.6                              | NG                               | Comparative Steel |
| 35 | AL-3 | 0.65              | 7.4                     | 0.5                    | 153.7                 | 0.14                                                                  | 11.7                              | NG                               | Comparative Steel |
|    | AM-3 | 0.83              | 21.1                    | 8.2                    | 189.8                 | 5.20                                                                  | 12.7                              | NG                               | Comparative Steel |
| 40 | AN-3 | 0.51              | 25.0                    | 1.3                    | 116.2                 | 3.59                                                                  | 1.9                               | NG                               | Comparative Steel |
|    | AO-3 | 0.61              | 15.6                    | 0.4                    | 131.8                 | 5.45                                                                  | 2.1                               | OK                               | Invention Steel   |
| 45 | AP-3 | 0.57              | 8.8                     | 1.0                    | 196.8                 | 1.11                                                                  | 6.8                               | OK                               | Invention Steel   |
|    | AQ-3 | 2.17              | 20.1                    | 1.4                    | 119.5                 | 23.93                                                                 | 21.2                              | NG                               | Comparative Steel |
| 50 | AA-4 | 0.66              | 19.7                    | 1.0                    | 100.3                 | 2.07                                                                  | 1.8                               | OK                               | Invention Steel   |
|    | AB-4 | 0.68              | 20.7                    | 1.1                    | 115.2                 | 10.50                                                                 | 1.1                               | OK                               | Invention Steel   |
| 55 | AC-4 | 1.04              | 24.4                    | 0.7                    | 107.4                 | 4.35                                                                  | 1.4                               | OK                               | Invention Steel   |
|    | AD-4 | 0.6               | 13.3                    | 0.9                    | 129.2                 | 7.44                                                                  | 1.8                               | OK                               | Invention Steel   |

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(continued)

|      | Carbide size (μm) | Ferrite grain size (μm) | Pearlite area rate (%) | Vickers hardness (HV) | No. of carbides at grain boundaries/ No. of carbides inside grains | Ratio of maximum crack length (%) | Impact resistance characteristic | Remarks           |
|------|-------------------|-------------------------|------------------------|-----------------------|--------------------------------------------------------------------|-----------------------------------|----------------------------------|-------------------|
| AE-4 | 0.24              | 12.2                    | 0.5                    | 126.5                 | 1.52                                                               | 5.4                               | OK                               | Invention Steel   |
| AF-4 | 0.36              | 18.3                    | 0.3                    | 115.8                 | 1.62                                                               | 2.7                               | OK                               | Comparative Steel |
| AG-4 | 0.73              | 19.3                    | 1.1                    | 107.0                 | 7.13                                                               | 1.1                               | OK                               | Invention Steel   |
| AH-4 | 0.52              | 21.9                    | 1.0                    | 105.2                 | 5.55                                                               | 1.2                               | OK                               | Invention Steel   |
| AI-4 | 0.78              | 24.1                    | 0.7                    | 106.3                 | 1.74                                                               | 2.2                               | OK                               | Invention Steel   |
| AJ-4 | 0.44              | 22.4                    | 8.4                    | 199.8                 | 2.88                                                               | 13.7                              | NG                               | Comparative Steel |
| AK-4 | 0.45              | 16.5                    | 0.3                    | 115.9                 | 1.92                                                               | 4.2                               | OK                               | Invention Steel   |
| AL-4 | 0.56              | 12.6                    | 0.4                    | 176.3                 | 1.74                                                               | 5.7                               | OK                               | Invention Steel   |
| AM-4 | 0.77              | 22.3                    | 0.1                    | 109.1                 | 3.38                                                               | 1.7                               | OK                               | Invention Steel   |
| AN-4 | 0.34              | 20.2                    | 1.3                    | 119.5                 | 2.05                                                               | 2.6                               | NG                               | Comparative Steel |
| AO-4 | 2.18              | 18.0                    | 1.2                    | 132.1                 | 4.03                                                               | 14.0                              | NG                               | Comparative Steel |
| AP-4 | 1.65              | 24.7                    | 1.0                    | 123.2                 | 7.68                                                               | 1.6                               | OK                               | Comparative Steel |
| AQ-4 | 0.52              | 16.4                    | 1.1                    | 122.2                 | 1.68                                                               | 4.9                               | OK                               | Invention Steel   |

**[0200]** In Comparative Steel AC-2, the finish hot rolling temperature is low and the productivity is low. In Comparative Steel AN-4, the finish hot rolling temperature is high, scale flaws form at the surface of the steel plate and cracks form from the flaw parts when impact load was given after cold forging and carburizing, quenching, and tempering, and the impact resistance characteristic falls.

**[0201]** In Invention Steel AB-3, the cooling rate at the ROT is slow, so a drop in productivity and formation of scale flaws are invited. In Invention Steels AJ-3 and AD-4, the cooling rate at the ROT is 100°C/sec, the outermost layer part of the steel plate is excessively cooled, and fine cracks are formed at the outermost layer part.

**[0202]** In Comparative Steel AN-3, the coiling temperature is low, large amounts of bainite, martensite, and other low temperature transformed structures are produced resulting in embrittlement, fractures frequently occur at the time of pay out of the hot rolled coil, and the productivity falls. Furthermore, at the sample taken from the cracked slab, the cold forging and impact resistance characteristic after carburizing, quenching, and tempering are inferior.

**[0203]** In Comparative Steel AH-3, the coiling temperature is high, bulky pearlite of the lamellar spacing is formed in the hot rolled structure, needle-shaped coarse carbides are high in thermal stability, and even after two-stage step type annealing, the above carbides remain in the steel plate, so the cold forgeability is low.

**[0204]** In Comparative Steel AF-4, the heating rate in the first stage annealing of the two-stage step type annealing is slow, so the productivity is low. In Comparative Steel AG-2, the heating rate in the first stage annealing is fast, so the

difference in temperature between the inside part and outer circumferential part of the coil becomes larger, scratches and seizing due to the difference in heat expansion occur, and the cold forging and impact resistance characteristic after carburizing, quenching, and tempering fall.

[0205] In Comparative Steel AA-2, the holding temperature in the first stage annealing (annealing temperature) is low, the coarsening of the carbides at the Ac1 point or less is insufficient, the thermal stability of the carbides becomes insufficient, the carbides remaining at the time of the second stage annealing decrease, the pearlite transformation cannot be suppressed in the structure after gradual cooling, and the cold forgeability falls.

[0206] In Comparative Steel AM-3, the first stage holding temperature (annealing temperature) is high, austenite is produced during the annealing, the stability of the carbides cannot be raised, and the cold forgeability and impact resistance characteristic after carburizing, quenching, and tempering fall. In Comparative Steel AF-2, the holding time in the first stage annealing is short, the stability of the carbides cannot be raised, and the cold forgeability is low. In Comparative Steel AO-4, the holding time in the first stage annealing is long and the productivity is low.

[0207] In Comparative Steel AP-4, the heating rate at the second stage annealing in the two-stage step type annealing is slow, so the productivity is low. In Comparative Steel AI-3, the heating rate at the second stage annealing is fast, so the temperature difference between the inside part and the outer circumferential part of the coil become greater, scratches and seizing occur due to the large difference in heat expansion due to transformation, and, when an impact load is given after carburizing, quenching, and tempering, fractures occur from the flaw parts and the impact resistance characteristics fall.

[0208] In Comparative Steel AL-3, the holding temperature in the second stage annealing (annealing temperature) is low, the amount of production of austenite is small, it is not possible to increase the number ratio of carbides at the ferrite grain boundaries, and the cold forgeability falls. In Comparative Steel AD-2, the holding temperature in the second stage annealing (annealing temperature) is high, the dissolution of carbides during annealing is promoted, and therefore it becomes difficult to cause the production of carbides at the grain boundaries after gradual cooling, and the cold forgeability and impact resistance characteristics after carburizing, quenching, and tempering fall.

[0209] In Comparative Steel AJ-4, the holding time in the second stage annealing is long and dissolution of carbides is promoted, so the cold forgeability is low. In Comparative Steel AQ-3, the cooling rate from the second stage annealing to 650°C is slow so the productivity is low and coarse carbides are formed in the structure after gradual cooling so cracks formed starting from the coarse carbides at the time of cold forging and the cold forgeability dropped. In Comparative Steel AP-2, the cooling rate from the second stage annealing to 650°C was slow, pearlite transformation occurred at the time of cooling, and the hardness increased, so the cold forgeability fell.

[0210] Here, FIG. 3 shows the relationship among the ratio of the number of carbides at the grain boundaries to the number of carbides in the grains, and the crack length and impact resistance characteristics of cold forging test pieces after carburizing, quenching, and tempering.

[0211] From FIG. 3, it will be understood that if the number ratio (=number of carbides at the grain boundaries/number of carbides in grains) exceeds 1, it is possible to keep down the ratio of the length of cracks introduced by cold forging and possible to obtain excellent impact resistance after carburizing, quenching, and tempering.

[0212] Further, FIG. 4 shows another relationship between the ratio of the number of carbides at the grain boundaries to the number of carbides in the grains and the crack length of cold forging test pieces and impact resistance characteristic after carburizing, quenching, and tempering. FIG. 4 is a view showing that it is possible to keep down crack length even in steel plate to which additional elements are added.

[0213] From FIG. 4, it will be understood that even if adding a suitable range of elements to steel plate, if the number ratio (=number of carbides at the grain boundaries/number of carbides in grains) exceeds 1, it is possible to keep down the ratio of the length of cracks introduced by cold forging and possible to obtain excellent impact resistance after carburizing, quenching, and tempering.

#### Industrial Applicability

[0214] As explained above, according to the present invention, it is possible to provide low carbon steel plate excellent in cold forgeability and impact resistance characteristic after carburizing, quenching, and tempering and a method of production of the same. The steel plate of the present invention is, for example, suitable as a material when forming a part by cold forging such as plate working to obtain a high cycle gear or other part, so the present invention has high industrial applicability.

#### Reference Signs List

#### [0215]

1. disk-shaped test material

2. cup-shaped test material
3. crack
4. sample
5. dropping weight
- L. maximum length of crack

## Claims

1. A steel plate being a low carbon steel plate having a chemical composition consisting of, by mass%,

C: 0.10 to 0.40%,  
Si: 0.01 to 0.30%,  
Mn: 0.30 to 1.00%,  
Al: 0.001 to 0.10%,  
Cr: 0.50 to 2.00%,  
Mo: 0.001 to 1.00%,  
P: 0.020% or less,  
S: 0.010% or less,  
N: 0.020% or less,  
O: 0.020% or less,  
Ti: 0.010% or less,  
B: 0.0005% or less,  
Sn: 0.050% or less,  
Sb: 0.050% or less,  
As: 0.050% or less,  
Nb: 0.10% or less,  
V: 0.10% or less,  
Cu: 0.10% or less,  
W: 0.10% or less,  
Ta: 0.10% or less,  
Ni: 0.10% or less,  
Mg: 0.050% or less,  
Ca: 0.050% or less,  
Y: 0.050% or less,  
Zr: 0.050% or less,  
La: 0.050% or less,  
Ce: 0.050%, and  
a balance of Fe and impurities,

wherein a metal structure of the steel plate has:

a carbide grain size of 0.4 to 2.0  $\mu\text{m}$ ;  
a pearlite area ratio of 6% or less; and  
a ratio of the number of carbides at ferrite grain boundaries to the number of carbides inside ferrite grains  
of more than 1, and

the steel plate has a Vickers hardness of 100HV to 180HV.

2. A method of production of the steel plate according to claim 1, the method of production comprising:

hot-rolling a steel slab with a chemical composition according to claim 1 to obtain a hot rolled steel plate, the hot-rolling in which finish hot-rolling is completed in a 650°C to 950°C temperature region;  
coiling the hot rolled steel plate at 400°C to 600°C;  
pickling the coiled hot rolled steel plate, and subjecting a first stage annealing to the pickled hot rolled steel plate, the first stage annealing in which the pickled hot rolled steel plate is heated, at a heating rate of 30°C/hour to 150°C/hour, up to an annealing temperature of 650°C to 720°C and the steel plate is held for 3 hours to 60 hours; then  
subjecting a second stage annealing to the hot rolled steel plate, the second stage annealing in which the hot

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rolled steel plate is heated, at a heating rate of 1°C/hour to 80°C/hour, up to an annealing temperature of 725°C to 790°C and the steel plate is held for 3 hours to 50 hours as second stage annealing; and cooling the annealed hot rolled steel plate to 650°C at a cooling rate of 1°C/hour to 100°C/hour.

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FIG. 1

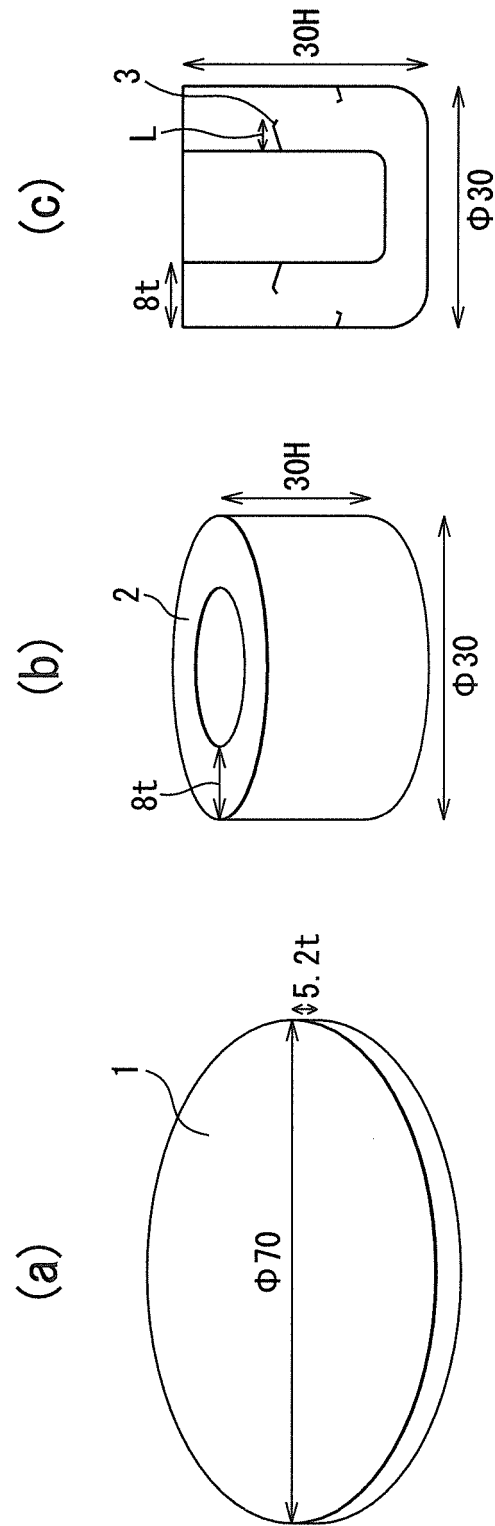


FIG. 2

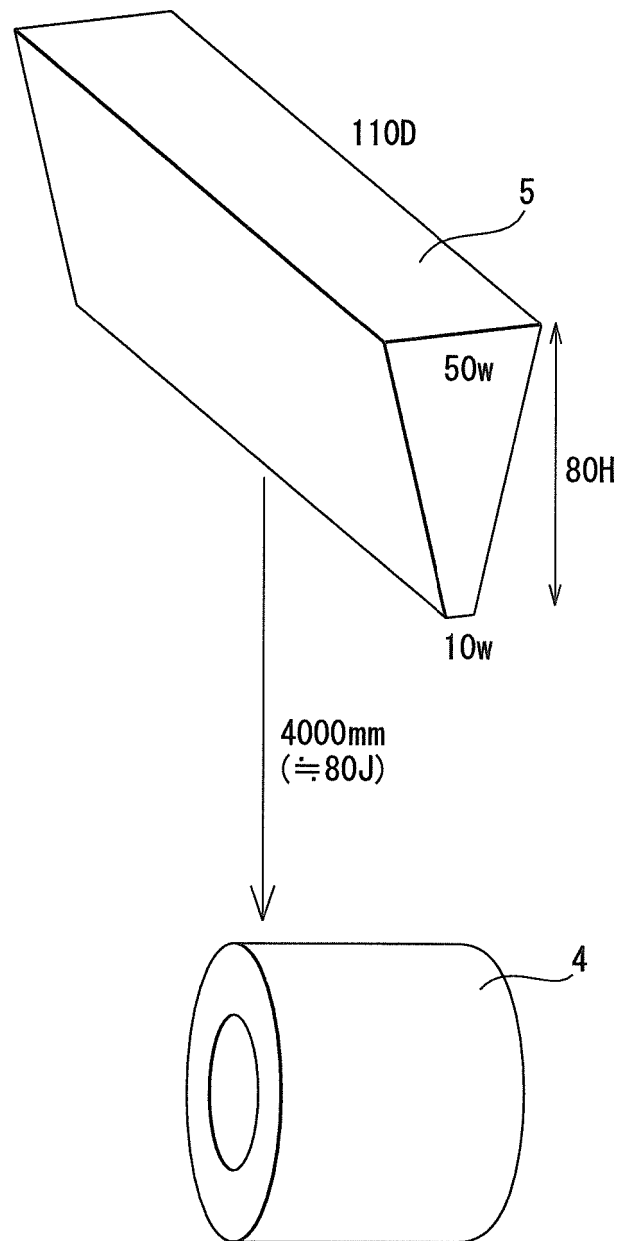


FIG. 3

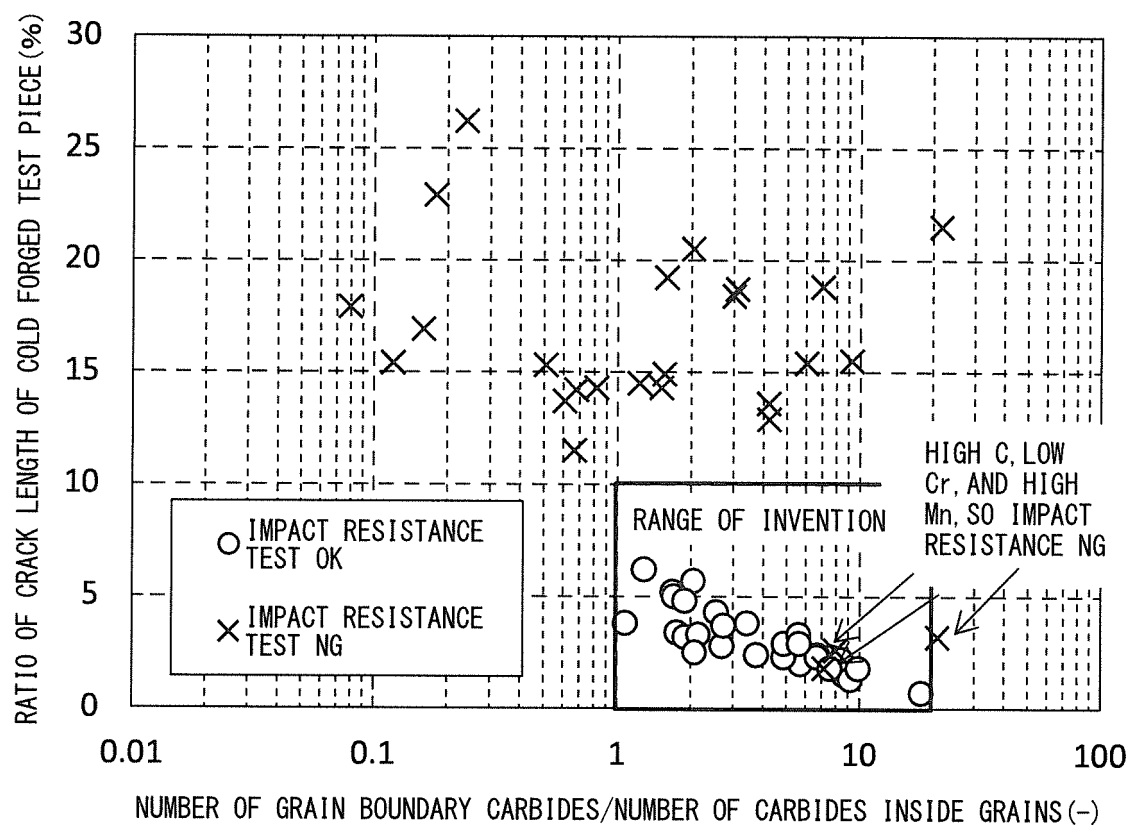
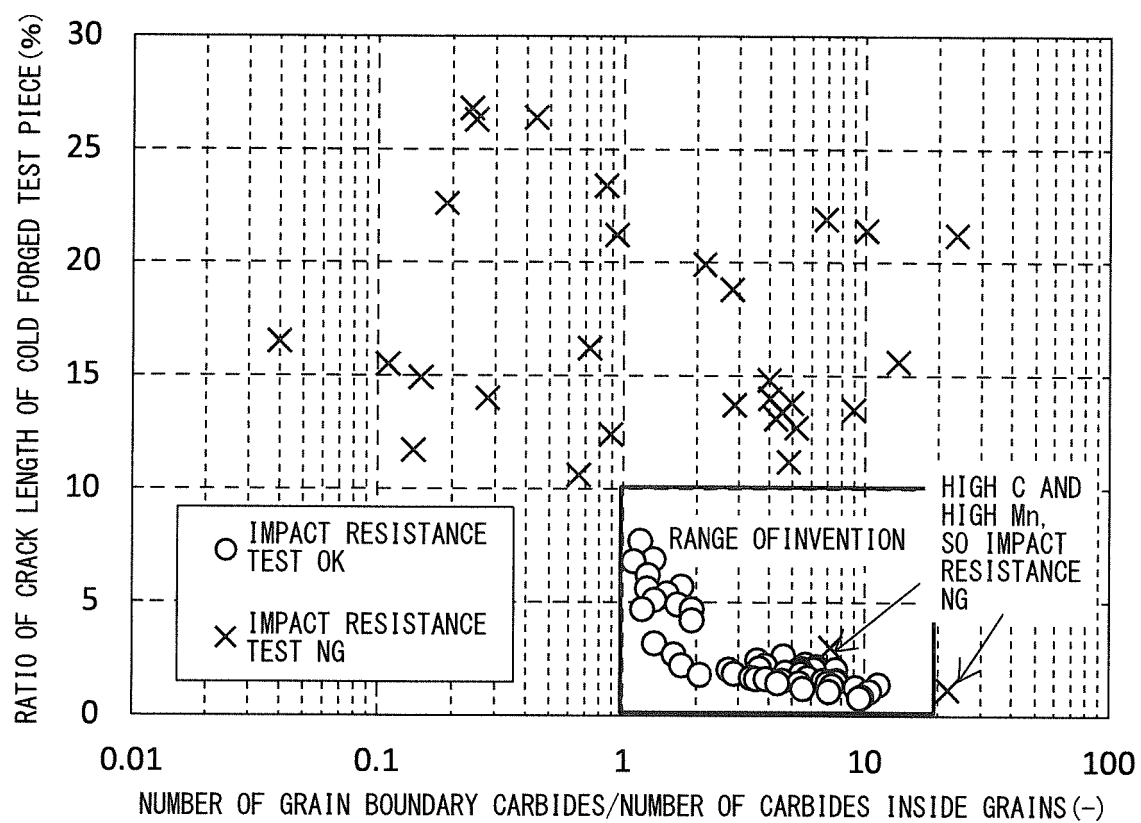


FIG. 4



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/065509

## A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C21D8/02(2006.01)i, C21D9/46(2006.01)i, C22C38/60(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60, C21D8/02-8/04, C21D9/46-9/48

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 1996-2016  
Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

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

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                 | Relevant to claim No. |
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| A         | WO 2007/111080 A1 (JFE Steel Corp.),<br>04 October 2007 (04.10.2007),<br>& JP 2007-291495 A & US 2010/0282376 A1<br>& EP 2000552 A2 & CN 101410544 A<br>& KR 10-2008-0106314 A & MX 2008012337 A<br>& CA 2646734 A1 & TW I317761 B | 1-2                   |
| A         | JP 2010-235977 A (Nisshin Steel Co., Ltd.),<br>21 October 2010 (21.10.2010),<br>(Family: none)                                                                                                                                     | 1-2                   |

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

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Date of the actual completion of the international search  
17 August 2016 (17.08.16)

Date of mailing of the international search report  
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Name and mailing address of the ISA/  
Japan Patent Office  
3-4-3, Kasumigaseki, Chiyoda-ku,  
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/065509

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Form PCT/ISA/210 (continuation of second sheet) (January 2015)

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