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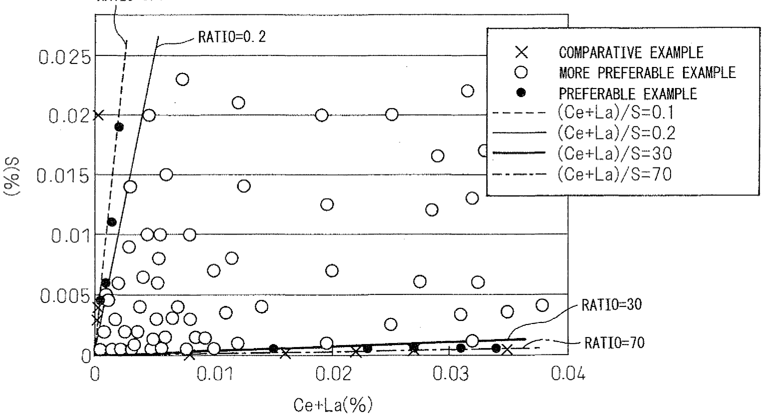
(54) HIGH-STRENGTH STEEL SHEET EXCELLENT IN STRETCH FLANGEABILITY AND FATIGUE PROPERTY

(57) The present invention provides high strength hot rolled steel plate superior in stretch flange formability and fatigue characteristics comprising steel plate containing C: 0.03 to 0.20%, Si: 0.08 to 1.5%, Mn: 1.0 to 3.0%, P: 0.05% or less, S: 0.0005% or more, N: 0.0005 to 0.01%, acid soluble A1: 0.01% or less, acid soluble Ti: less than 0.008%, and a total of one or both of Ce or La: 0.0005 to 0.04%, having a balance of iron and unavoidable impurities and having a number ratio of 20% or less of stretched inclusions present in the steel plate having a circle equivalent diameter of 1 μm or more and a long axis/short axis of 5 or more.

Fig.1



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Description

TECHNICAL FIELD

[0001] The present invention relates to high strength hot rolled steel plate superior in stretch flange formability and fatigue characteristics suitable as a material for members of an automobile chassis.

BACKGROUND ART

[0002] From the viewpoint of improvement of automobile safety and improvement of the fuel economy leading in turn to environmental protection, the demands for increasing the strength and reducing the weight of the hot rolled steel plate used for automobiles have been growing stronger. Among auto parts, in particular, the weight of frames, arms, etc. called "chassis parts" accounts for a high ratio of the weight of the vehicle as a whole, so the materials used for such locations are being made higher in strength and smaller in thickness to enable lighter weight. Further, the materials used for such chassis parts are required to have high fatigue characteristics from the viewpoint of durability with respect to the vibration during driving.

[0003] However, along with the higher strength and fatigue resistance, the hole expandability tends to drop in the same way as the ductility. When using high strength steel plate for the complicatedly shaped chassis parts etc. of automobiles, this hole expandability becomes an important matter for study.

[0004] For this reason, several types of steel plates designed to achieve both the mechanical strength characteristics and the fatigue characteristics and hole expandability (workability) have been proposed. For example, Japanese Patent Publication (A) No. 11-199973 proposes steel plate comprised of composite structure steel plate of a ferrite phase and a martensite phase in which fine Cu is precipitated or a solid solution is dispersed (in general called "DP steel plate"). In the technology disclosed in this Japanese Patent Publication (A) No. 11-199973, it was found that the solid solution Cu or CU precipitates comprised of Cu alone and having a particle size of 2 nm or less are extremely effective for improving the fatigue characteristics and do not impair the workability either. The ratios of compositions of the various ingredients were limited based on this.

[0005] It is known that such DP steel plate is superior in the balance of strength and ductility and in the fatigue characteristics, but the stretch flange formability, evaluated by a hole expansion test, remains inferior. One of the reasons is believed to be that DP steel plate is a composite of a soft ferrite phase and a hard martensite phase, so at the time of hole expansion, the boundary parts of the two phases cannot keep up with the deformation and easily become starting points for breakage.

[0006] As opposed to this, high strength hot rolled steel plate satisfying not only the fatigue characteristics, but also the tough demands for stretch flange formability for materials of recent wheels or chassis parts has been proposed (for example, see Japanese Patent Publication (A) No. 2001-200331). In the technology disclosed in Japanese Patent Publication (A) No. 2001-200331, the C is made as low as possible to make the main phase a bainite structure and introduce a solution strengthened or precipitation strengthened ferrite structure in a suitable volume ratio, reduce the difference in hardness of the ferrite and bainite, and further avoid formation of coarse carbides.

DISCLOSURE OF THE INVENTION

[0007] High strength hot rolled steel plate having a steel plate structure of mainly a bainite phase and suppressing the formation of coarse carbides such as disclosed in said Japanese Patent Publication (A) No. 2001-200331 does indeed exhibit a superior stretch flange formability, but cannot necessarily be said to be superior in fatigue characteristics compared with DP steel plate containing Cu. Further, with just suppressing the formation of coarse carbides, it is not possible to prevent the occurrence of cracks at the time of extreme hole expansion. According to the research of the inventors, the cause is the presence of stretched sulfide-based inclusions mainly comprised of MnS in the steel plate. Upon repeated deformation, internal defects form near the stretched coarse MnS-based inclusions present at the surface layer or its vicinity and propagate as cracks to thereby cause deterioration of the fatigue characteristics. Again, stretched coarse MnS-based inclusions easily become starting points of cracking at the time of hole expansion. For this reason, it is preferable not to allow the MnS-based inclusions in the steel to stretch as much as possible but to make them finely spherical.

[0008] However, Mn is an element effectively contributing to the increase in strength of a material along with C and Si, but with high strength steel plate, to secure strength, the general practice has been to set the concentration of Mn high. Furthermore, if not performing the overlapping treatment of desulfurization in the secondary refining process, an S concentration of 50 ppm or more ends up being included. For this reason, a cast slab usually contains MnS. If the cast slab is hot rolled and cold rolled, the MnS easily deforms, so becomes stretched MnS-based inclusions. These become causes lowering the fatigue characteristics and stretch flange formability (hole expandability). However, no example has been found proposing hot rolled steel plate superior in stretch flange formability and fatigue characteristics from the viewpoint of control of the precipitation and deformation of MnS.

[0009] Therefore, the present invention was proposed in consideration of the above points and has as its object the provision of high strength steel plate superior in stretch flange formability and fatigue characteristics improving the stretch flange formability and the fatigue characteristics by causing the precipitation of fine MnS in the cast slab and making this disperse as fine spherical inclusions not deformed and not easily becoming starting points of cracking in the steel plate at the time of rolling.

[0010] To solve the problems described above, the inventors engaged in in-depth studies on the method of making fine MnS precipitate in cast slabs and making this disperse as fine spherical inclusions not deformed and not easily becoming starting points of cracking at the time of rolling and to clarify the additive elements not causing deterioration of the fatigue characteristics. As a result, they learned that MnS precipitates on the fine, hard Ce oxides, La oxides, cerium oxysulfides, and lanthanum oxysulfides formed due to deoxidation due to addition of Ce and La, the thus precipitated MnS is resistant to deformation at the time or rolling as well, so the amount of stretched coarse MnS in the steel plate is remarkably reduced and, at the time of repeated deformation or at the time of hole expansion, these MnS-based inclusions do not easily become starting points of cracking or routes for crack propagation and that this leads to an improvement in the fatigue resistance etc.

[0011] The high strength steel plate superior in stretch flange formability and fatigue characteristics according to the present invention has as its gist the following:

(1) A high strength steel plate superior in stretch flange formability and fatigue characteristics characterized by comprising steel plate containing, by mass%, C: 0.03 to 0.20%, Si: 0.08 to 1.5%, Mn: 1.0 to 3.0%, P: 0.05% or less, S: 0.0005% or more, N: 0.0005 to 0.01%, acid soluble Al: 0.01% or less, acid soluble Ti: less than 0.008%, and a total of one or both of Ce or La: 0.0005 to 0.04%, having a balance of iron and unavoidable impurities, and having a number ratio of 20% or less of stretched inclusions present in the steel plate having a circle equivalent diameter of 1 μm or more and a long axis/short axis of 5 or more.

(2) A high strength steel plate superior in stretch flange formability and fatigue characteristics characterized by comprising steel plate containing, by mass%, C: 0.03 to 0.20%, Si: 0.08 to 1.5%, Mn: 1.0 to 3.0%, P: 0.05% or less, S: 0.0005% or more, N: 0.0005 to 0.01%, acid soluble Al: 0.01% or less, acid soluble Ti: less than 0.008%, and a total of one or both of Ce or La: 0.0005 to 0.04%, having a balance of iron and unavoidable impurities, and having inclusions in the steel plate comprised of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated in a number ratio of 10% or more.

(3) A high strength steel plate superior in stretch flange formability and fatigue characteristics characterized by comprising steel plate containing, by mass%, C: 0.03 to 0.20%, Si: 0.08 to 1.5%, Mn: 1.0 to 3.0%, P: 0.05% or less, S: 0.0005% or more, N: 0.0005 to 0.01%, acid soluble A1: 0.01% or less, acid soluble Ti: less than 0.008%, and a total of one or both of Ce or La: 0.0005 to 0.04%, having a balance of iron and unavoidable impurities, and having a volume number ratio of $1.0 \times 10^4/mm^3$ or less of stretched inclusions present in the steel plate having a circle equivalent diameter of 1 μm or more and a long axis/short axis of 5 or more.

(4) A high strength steel plate superior in stretch flange formability and fatigue characteristics characterized by comprising steel plate containing, by mass%, C: 0.03 to 0.20%, Si: 0.08 to 1.5%, Mn: 1.0 to 3.0%, P: 0.05% or less, S: 0.0005% or more, N: 0.0005 to 0.01%, acid soluble A1: 0.01% or less, acid soluble Ti: less than 0.008%, and a total of one or both of Ce or La: 0.0005 to 0.04%, having a balance of iron and unavoidable impurities, and having a volume number density of inclusions in the steel plate comprised of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated in a volume number density of $1.0 \times 10^3/mm^3$ or more.

(5) A high strength steel plate superior in stretch flange formability and fatigue characteristics characterized by comprising steel plate containing, by mass%, C: 0.03 to 0.20%, Si: 0.08 to 1.5%, Mn: 1.0 to 3.0%, P: 0.05% or less, S: 0.0005% or more, N: 0.0005 to 0.01%, acid soluble Al: 0.01% or less, acid soluble Ti: less than 0.008%, and a total of one or both of Ce or La: 0.0005 to 0.04%, having a balance of iron and unavoidable impurities, and having an average circle equivalent diameter of 10 μm or less of stretched inclusions present in the steel plate having a circle equivalent diameter of 1 μm or more and a long axis/short axis of 5 or more.

(6) A high strength steel plate superior in stretch flange formability and fatigue characteristics characterized by comprising steel plate containing, by mass%, C: 0.03 to 0.20%, Si: 0.08 to 1.5%, Mn: 1.0 to 3.0%, P: 0.05% or less, S: 0.0005% or more, N: 0.0005 to 0.01%, acid soluble Al: 0.01% or less, acid soluble Ti: less than 0.008%, and a total of one or both of Ce or La: 0.0005 to 0.04%, having a balance of iron and unavoidable impurities, having inclusions present in the steel plate comprising an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated, and having the inclusions include, in average composition, a total of one or both of Ce or La in 0.5 to 50 mass%.

(7) A high strength steel plate superior in stretch flange formability and fatigue characteristics characterized by comprising steel plate containing, by mass%, C: 0.03 to 0.20%, Si: 0.08 to 1.5%, Mn: 1.0 to 3.0%, P: 0.05% or less,

S: 0.0005% or more, N: 0.0005 to 0.01%, acid soluble Al: 0.01% or less, acid soluble Ti: less than 0.008%, and a total of one or both of Ce or La: 0.0005 to 0.04%, having a balance of iron and unavoidable impurities, and having a (Ce+La)/S ratio of 0.1 to 70.

(8) A high strength steel plate superior in stretch flange formability and fatigue characteristics as set forth in any one of (1) to (7) characterized by comprising steel plate containing, by mass%, one or more of any of Nb: 0.01 to 0.10%, V: 0.01 to 0.05%, Cr: 0.01 to 0.6%, Mo: 0.01 to 0.4%, and B: 0.0003 to 0.03% and having a balance of iron and unavoidable impurities.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a view showing the relationship of Ce+La (%)and S (%).

BEST MODE FOR CARRYING OUT THE INVENTION

[0013] Below, as the best mode for carrying out the present invention, high strength steel plate superior in stretch flange formability and fatigue characteristics will be studied in detail. Below, the "mass%" in the composition will be simply described as "%".

[0014] First, the experiments leading to the completion of the present invention will be explained.

[0015] The inventors deoxidized molten steel containing C: 0.07%, Si: 0.20, Mn: 1.2%, P: 0.01% or less, S: 0.005%, and N: 0.003% and having a balance of Fe using various elements and produced steel ingots. They hot rolled the obtained steel ingots to obtain 3 mm hot rolled steel plate. They then used the thus produced hot rolled steel plate for hole expansion tests and fatigue tests and investigated the number density, form, and average composition of the inclusions in the steel plate.

[0016] As a result, they learned that steel plate not deoxidized much at all by Al, but given Si, then given at least Ce and La for deoxidation was the most superior in stretch flange formability and fatigue characteristics. The reason is that MnS precipitates on fine, hard Ce oxides, La oxides, cerium oxysulfides, and lanthanum oxysulfides formed due to deoxidation due to addition of Ce and La, the precipitated MnS is resistant to deformation at the time of rolling as well, and therefore the stretched coarse MnS remarkably decreases in the steel plate. As a result, these MnS-based inclusions do not easily become starting points of cracking or routes of crack propagation at the time of repeated deformation or at the time of hole expansion. This leads to improvement of the fatigue resistance etc. as explained above.

[0017] Note that the reason why the Ce oxides, La oxides, cerium oxysulfides, and lanthanum oxysulfides become finer is that the SiO_2-based inclusions first formed by Si deoxidation are reduced and broken up by the later added Ce and La to form fine Ce oxides, La oxides, cerium oxysulfides, and lanthanum oxysulfides and, furthermore, the interfacial energy between the formed Ce oxides, La oxides, cerium oxysulfides, and lanthanum oxysulfides themselves and the molten steel is low, so clustering after formation is also suppressed.

[0018] Based on the findings obtained from these experimental studies, as explained below, the inventors studied the conditions for the chemical ingredients of steel plate and completed the present invention.

[0019] Below, the reasons for limiting the chemical ingredients in the present invention will be explained.

C: 0.03 to 0.20%

C is the most basic element for controlling the quenchability and strength of steel. It increases the hardness and depth of the quenched hardened layer and effectively contributes to the improvement of the fatigue strength. That is, this C is an essential element for securing the strength of steel plate. To obtain high strength steel plate, at least 0.03% is necessary. However, if this C is excessively included, the C is fixed by the formation of Ti carbides like in the past or even if using cooling conditions, a cementite phase ends up being formed. This cementite phase causes work hardening of the steel plate and is not preferable for improvement of the stretch flange formability characteristics. For this reason, in the present invention, from the viewpoint of improving the workability, the concentration of C is made 0.20% or less.

Si: 0.08 to 1.5%

[0020] Si becomes an important deoxidizing element in molten steel to which Al or Ti are not added as much as possible like in the present invention, so is extremely important in the present invention. Further, Si has the function of increasing the nucleation sites of austenite at the time of quenching heating and suppressing the grain growth of the austenite and of making the grain size of the quenched hardened layer finer. This Si suppresses carbide formation and suppresses the drop in grain boundary strength due to carbides. Furthermore, this Si is effective against the formation of a bainite structure as well and plays an important role in terms of securing the strength of the material as a whole. To lower the concentration of solute oxygen in the molten steel and cause the formation of SiO_2-based inclusions once (to reduce the SiO_2-based inclusions by the later added Ce and La and thereby make the inclusions finer), it is necessary to add Si in 0.08% or more. For this reason, in the present invention, the lower limit of Si was made 0.08%. As opposed to this, if the Si concentration is too high, the concentration of SiO_2 in the inclusions becomes higher and large inclusions become easier to form or the toughness and ductility become extremely poor and the surface decarburization and surface flaws increase, so the fatigue characteristics conversely deteriorate. In addition to this, if excessively adding Si, the weldability and the ductility are detrimentally affected. For this reason, in the present invention, the upper limit of the Si was made 1.5%.

Mn: 1.0 to 3.0%

[0021] Mn is an element useful for deoxidization in the steelmaking stage. Along with C and Si, it is an element effective for raising the strength of the steel plate. To obtain this effect, it is necessary to include this Mn in 1.0% or more. However, if Mn is included in an amount over 3.0%, the ductility drops due to the segregation of Mn and solution strengthening. Further, the weldability and matrix toughness also deteriorate, so the upper limit of Mn is made 3.0%.

P: 0.05% or less

[0022] P is effective in the point of acting as a substitution type solution strengthening element smaller than Fe atoms, but segregates at the grain boundaries of the austenite and causes a drop in the grain boundary strength, so causes a drop in the torsional fatigue strength. Deterioration of the workability is a concern, so the amount is made 0.05% or less. Further, if not necessary for solution strengthening, P does not have to be added. The lower limit value of P therefore includes 0%.

S: 0.0005% or more

[0023] S segregates as an impunity. S forms coarse stretched inclusions of MnS and causes deterioration in the stretch flange formability, so as low a concentration as possible is desirable. In the past, to secure stretch flange formability, the concentration of S had to be made an ultralow one of less than 0.0005%. However, in the present invention, fine MnS is made to precipitate on the hard Ce oxides, La oxides, cerium oxysulfides, and lanthanum oxysulfides to make deformation at the time of rolling difficult and prevent stretching of the inclusions, so the upper limit value of the concentration of S is not particularly defined.

[0024] Further, to reduce the S concentration to a level equal to the past of less than 0.0005%, it is necessary to considerably strengthen the desulfurization in the secondary refining. The cost of the desulfurization for achieving this concentration becomes too high and the effect of controlling the shape of the MnS becomes difficult to obtain, so the lower limit value of the S concentration is made 0.0005%.

N: 0.0005 to 0.01%

[0025] N is an element which is unavoidably mixed in the steel since nitrogen in the air is taken in during the melting process. N forms nitrides together with Al, Ti, etc. to promote the increased fineness of the matrix structure. However, if overly adding this N, even with a fine amount of Al or a fine amount of Ti, coarse precipitates are formed and the stretch flange formability is degraded. For this reason, in the present invention, the upper limit of the concentration of N was made 0.01%. On the other hand, to make the concentration of N less than 0.0005%, the cost becomes high, so 0.0005% is made the lower limit.

Acid soluble Al: 0.01% or less

[0026] With acid soluble Al, the oxides easily cluster and become coarse, so this is preferably suppressed as much as possible to prevent deterioration of the stretch flange formability and the fatigue characteristics. However, use as a preliminary deoxidizing material up to 0.01% is allowed. This is because if the acid soluble Al concentration is over 0.01%, the Al_2O_3 content in the inclusions exceeds 50% and the inclusions cluster. From the viewpoint of preventing clustering, the lower the acid soluble Al concentration the better. The lower limit value includes 0%. Further, the "acid soluble Al concentration" measures the concentration of Al dissolved in an acid, so is a method of analysis utilizing the fact that solute Al dissolves in acid while Al_2O_3 does not dissolve in acid. Here, the "acid" means, for example, a mixed acid of a mixture of hydrochloric acid in 1 part, nitric acid in 1 part, and water in 2 parts (mass ratio). Using such an acid, it is possible to separate acid soluble Al and Al_2O_3 not dissolving in an acid and measure the acid soluble Al concentration.

Acid soluble Ti: less than 0.008%

[0027] With acid soluble Ti as well, the oxides easily cluster and become coarse. Further, this bonds with the N in the steel to form coarse TiN inclusions. Therefore, the acid soluble Ti is made less than 0.008%. The lower limit value includes 0%. Further, the "acid soluble Ti concentration" measures the concentration of Ti dissolved in an acid, so is a method of analysis utilizing the fact that solute Ti dissolved in acid, while Ti oxide does not dissolve in acid. Here, the "acid" means, for example, a mixed acid of a mixture of hydrochloric acid in 1 part, nitric acid in 1 part, and water in 2 parts (mass ratio). Using such an acid, it is possible to separate acid soluble Ti and Ti oxides not dissolving in an acid and measure the acid soluble Ti concentration.

Total of one or both of Ce or La: 0.0005 to 0.04%

[0028] Ce and La have the effect of reducing the SiO_2 produced by Si deoxidation and forming inclusions having Ce oxides (for example, Ce_2O_3, CeO_2), cerium oxysulfides (for example, Ce_2O_2S), La oxides (for example, La_2O_3, LaO_2), lanthanum oxysulfides (for example, La_2O_2S), Ce oxide-La oxides, or cerium oxysulfide-lanthanum oxysulfides as main phases (50% or more as a rule of thumb) which easily become Mn precipitating sites and are hard, fine, and resistant to deformation at the time of rolling.

[0029] Here, these inclusions sometimes also partially contain MnO, SiO_2, or Al_2O_3 depending on the deoxidizing conditions, but if the main phase is such an oxide, they will sufficiently function as MnS precipitating sites and the effect of increasing the fineness and hardness of the inclusions will not be impaired. To obtain such inclusions, the total concentration of the one or both of Ce or La must be made 0.0005% to 0.04%. If the total concentration of the one or both of Ce or La is less than 0.0005%, the SiO_2 inclusions cannot be reduced, while if over 0.04%, large amounts of cerium oxysulfide and lanthanum oxysulfide are produced and form coarse inclusions which degrade the stretch flange formability and fatigue characteristics.

Nb: 0.01 to 0.10%

[0030] Nb forms carbides, nitrides, and carbonitrides with C or N to promote the increased fineness of the matrix structure. To obtain this effect, at least 0.01% is necessary. However, even if included in a large amount over 0.10%, the effect is saturated and the cost becomes high, so 0.10% is made the upper limit.

V: 0.01 to 0.05%

[0031] V forms carbides, nitrides, and carbonitrides with C or N to promote the increased fineness of the matrix structure. To obtain this effect, at least 0.01% is necessary. However, even if included in a large amount over 0.05%, the effect is saturated and the cost becomes high, so 0.05% is made the upper limit.

Cr: 0.01 to 0.6%

[0032] Cr may be included as necessary to improve the quenchability of steel and secure strength of the steel plate. To obtain this effect, at least 0.01% is necessary. However, inclusion of a large amount conversely degrades the balance of strength and ductility. Therefore, 0.6% is made the upper limit.

Mo: 0.01 to 0.4%

[0033] Mo may be included as necessary to improve the quenchability of steel and secure strength of the steel plate. To obtain this effect, at least 0.01% is necessary. However, inclusion of a large amount conversely degrades the balance of strength and ductility. Therefore, 0.4% is made the upper limit.

B: 0.0003 to 0.003%

[0034] B may be included as necessary to improve the quenchability of steel, strengthen the grain boundaries, and improve the workability. To obtain this effect, at least 0.0003% is necessary. However, inclusion of a large amount conversely detracts from the cleanliness of the steel and degrades the ductility. Therefore, 0.003% is made the upper limit.

[0035] Next, the conditions of presence of the inclusions in the steel plate of the present invention will be explained. Further, the "steel plate" means the plate after rolling obtained by hot rolling or further cooling rolling.

[0036] To obtain the steel plate superior in stretch flange formability and fatigue characteristics, it is important to reduce as much as possible the stretched coarse MnS-based inclusions easily becoming starting points of cracking and routes for crack propagation in the steel plate. The inventors discovered through experiments that MnS-based inclusions with a circle equivalent diameter of less than 1 μm are harmless as starting points of cracking and do not cause deterioration of the stretch flange formability or fatigue characteristics. Further, inclusions with a circle equivalent diameter of 1 μm or more are easily observed by a scan type electron microscope (SEM) etc., so the inventors investigated the shape and composition of inclusions in steel plate with a circle equivalent diameter of 1 μm or more and evaluated the state of distribution of the MnS-based inclusions. Here, the "circle equivalent diameter" is defined as the (long axis x short axis)$^{0.5}$ found from the long axis and short axis of inclusions observed in cross-section.

[0037] Note that the upper limit of the circle equivalent diameter of the MnS-based inclusions is not particularly limited, but in practice MnS-based inclusions of about 1 mm are observed.

[0038] The number ratio of the stretched inclusions is found by analyzing the composition of a plurality of randomly selected inclusions (for example 50 or so) with a circle equivalent diameter of 1 μm or more using an SEM and measuring the long axes and short axes of the inclusions from the SEM image. Here, when defining "stretched inclusions" as inclusions with a long axis/short axis (stretch ratio) of 5 or more, the number ratio of the stretched inclusions can be found by dividing the detected number of stretched inclusions by the total number of inclusions investigated (in the above example, 50 or so).

[0039] Note that the stretch ratio of the inclusions was made 5 or more because the inclusions with a stretch ratio of 5 or more in comparative steel plate not containing La are almost all MnS-based inclusions. Further, the upper limit of the stretch ratio of the MnS-based inclusions is not particularly limited, but in practice MnS-based inclusions with a stretch ratio of 50 or so are sometimes observed.

[0040] As a result, it was learned that with steel plate controlled in form to a number ratio of stretched inclusions with a stretch ratio of 5 or more of 20% or less, the stretch flange formability and the fatigue characteristics are improved. That is, if the number ratio of the stretched inclusions with a stretch ratio of 5 or more exceeds 20%, the number of MnS-based stretched inclusions easily becoming starting points of cracking becomes too large and the stretch flange formability and the fatigue characteristics drop. In the present invention, the number ratio of stretched inclusions with a stretch ratio of 5 or more is made 20% or less. Further, the stretch flange formability and the fatigue characteristics are better the small the number of stretched MnS-based inclusions, so the lower limit value of the number ratio of the stretched inclusions with a stretch ratio of 5 or more includes 0%.

[0041] Here, the lower limit value of the number ratio of stretched inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 5 or more being 0% means when there are inclusions with a circle equivalent diameter of 1 μm or more, but none with a stretch ratio of 5 or more or when there are stretched inclusions with a stretch ratio of 5 or more, but all have a circle equivalent diameter of less than 1 μm.

[0042] Further, in steel plate controlled to a form with a number ratio of the stretched inclusions with a stretch ratio of 5 or more of 20% or less, in accordance with this, MnS precipitates on the oxide or oxysulfide of one or both of Ce or La. The form of the inclusions is not particularly limited so long as MnS precipitates on an oxide or oxysulfide of one or both of Ce or La, but usually is an oxide or oxysulfide of one or both of Ce or La as core around which the MnS precipitates.

[0043] Further, inclusions comprised of an oxide or oxysulfide of one or both of Ce or La on which MnS has precipitated are resistant to deformation even at the time of rolling, so become unstretched shapes even in the steel plate, that is, substantially spherical inclusions.

[0044] Here, the spherical inclusions judged as not stretched are not particularly limited, but may be inclusions in the steel plate with a stretch ratio of 3 or less, preferably inclusions with a ratio of 2 or less. This is because at the cast slab stage before the rolling, the stretch ratio of the inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated was 3 or less. Further, if spherical inclusions judged as not stretched are completely spherical, the stretch ratio would become 1, so the lower limit of the stretch ratio is 1.

[0045] The number ratio of the inclusion was investigated by a method similar to the investigation of the number ratio of the stretched inclusion. As a result, it was learned that in steel plate controlled in precipitation to have a number ratio of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated of 10% or more, the stretch flange formability and the fatigue characteristics are improved. If the number ratio of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated becomes less than 10%, in accordance with this, the number ratio of MnS-based stretched inclusions becomes too large and the stretch flange formability and the fatigue characteristics fall. For this reason, the number ratio of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated is made 10% or more. Further, the stretch flange formability and the fatigue characteristics become better with a large amount of MnS precipitated on oxides or oxysulfides of one or both of Ce or La, so the upper limit value of the number ratio includes 100%.

[0046] Note that inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated are resistant to deformation even at the time of rolling, so the circle equivalent diameter is not particularly limited, but may be 1 μm or more. However, if too large, the inclusions may form starting points of cracking, so the upper limit is preferably 50 μm or so.

[0047] On the other hand, not only are the inclusions resistant to deformation even at the time of rolling, but when the circle equivalent diameter is less than 1 μm, they will also not form starting points of cracking, so the lower limit of the circle equivalent diameter is not particularly defined.

[0048] Next, as a condition of presence of inclusions in the steel plate of the present invention explained above, the number density of inclusions per unit volume is defined.

[0049] The distribution of particle size of the inclusions was obtained by SEM evaluation of the electrolyzed surface by the speed method. "SEM evaluation of the electrolyzed surface by the speed method" means polishing the surface of a sample piece, then electrolyzing it by the speed method and directly evaluating the sample surface by an SEM to evaluate the size and number density of the inclusions. Note that the "speed method" is the method of using 10% acetyl acetone-1% tetramethyl ammonium chloride-methanol to electrolyze the sample surface and extract the inclusions. As the amount of electrolysis, 1C per 1 cm^2 area of the sample surface was electrolyzed. An SEM image of the thus electrolyzed surface was processed to find the distribution of frequency (number) with respect to the circle equivalent diameter. From this distribution of frequency of the particle size, the average circle equivalent diameter was calculated. Further, the frequency was divided by the depth found by the area of the observed field and the amount of electrolysis to calculate the number density of inclusions per volume.

[0050] The inventors evaluated the volume number density of inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 5 or more becoming starting points of cracking and degrading the stretch flange formability and the fatigue characteristics and as a result learned that if $1.0 \times 10^4/mm^3$ or less, the stretch flange formability and the fatigue characteristics are improve. If the volume number density of stretched inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 5 or more is over $1.0 \times 10^4/mm^3$, the number density of the MnS-based stretched inclusions easily becoming starting points of cracking becomes too large and the and the stretch flange formability and the fatigue characteristics fall, so the volume number density of stretched inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 5 or more is made $1.0 \times 10^4/mm^3$ or less. Further, the stretch flange formability and the fatigue characteristics are better the smaller the stretched MnS-based inclusions, so the lower limit value of the volume number density with a circle equivalent diameter 1 μm or more and with a stretch ratio of 5 or more includes 0%.

[0051] Here, the lower limit value of the volume number density of stretched inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 5 or more being 0% means the same as the above.

[0052] Further, in steel plate controlled to a form with a volume number density of stretched inclusions with a diameter of 1 μm or more and with a stretch ratio of 5 or more of $1.0 \times 10^4/mm^3$ or less, in accordance with this, the unstretched

MnS-based inclusions become a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated. The shape was substantially spherical inclusions.

[0053] The form of the inclusions, in the same way as the above, is not particularly limited so long as it is an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated, but usually it is an oxide or oxysulfide of one or both of Ce or La as a core around which MnS is precipitated.

[0054] Further, the "spherical inclusions" is not particularly limited, but refers to inclusions in the steel plate with a stretch ratio of 3 or less, preferably inclusions with a ratio of 2 or less. Here, if completely spherical, the stretch ratio becomes 1, so the lower limit of the stretch ratio is 1.

[0055] The inventors investigated the volume number density of such inclusions and as a result learned that with steel plate controlled in precipitation to give a volume number density of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La as a core around which MnS is precipitated of $1.0\times10^3/mm^3$ or more, the stretch flange formability and the fatigue characteristics are improved. If the volume number density of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated is less than $1.0\times10^3/mm^3$, in accordance with this, the number ratio of the MnS-based stretched inclusions becomes too large and the stretch flange formability and the fatigue characteristics fall, so the volume number density of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated is defined as $1.0\times10^3/mm^3$ or more. Further, the stretch flange formability and the fatigue strength become better the more the MnS precipitated around cores of an oxide or oxysulfide of one or both of Ce or La, so the upper limit value of the volume number density is not particularly defined.

[0056] Note that the circle equivalent diameter of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated, in the same way as above, is not particularly limited, but may be 1 μm or more. However, if this circle equivalent diameter is too large, the inclusions are liable to become starting points of cracking, so the upper limit is preferably 50 μm or so.

[0057] On the other hand, when the circle equivalent diameter of the inclusions is less than 1 μm, there is no problem at all, so the lower limit is not particularly defined.

[0058] Next, as a condition of presence of stretched inclusions in the steel plate of the present invention described above, the upper limit of the circle equivalent diameter is defined. Specifically, the inventors evaluated the average circle equivalent diameter of inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 5 or more forming starting points of cracking and degrading the stretch flange formability and fatigue characteristics and as a result learned that if the average circle equivalent diameter of the stretched inclusions is 10 μm or less, the stretch flange formability and fatigue characteristics are improved. The inventors took note of the fact that along with an increase in the number ratio of the stretched inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 5 or more, the average circle equivalent diameter of the stretched inclusions becomes larger and defined the average circle equivalent diameter of the stretched inclusions as an indicator. They guessed that as the amount of Mn or S in the steel increases, the number of MnS formed increases and the formed MnS becomes coarser in size.

[0059] Therefore, if the stretched inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 5 or more exceed 10 μm, in accordance with this, the number ratio of the stretched inclusions exceeds 20%, so the number ratio of coarse MnS-based stretched inclusions easily becoming starting points of cracking becomes too large and the stretch flange formability and fatigue characteristics fall, therefore the average circle equivalent diameter of the stretched inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 5 or more is made 10 μm or less.

[0060] Note that defining the average circle equivalent diameter of stretched inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 5 or more as 10 μm or less means the case where inclusions with a circle equivalent diameter of 1 μm or more are present in the steel plate, so the lower limit value of the circle equivalent diameter becomes 1 μm.

[0061] On the other hand, as a condition of presence of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated in the steel plate of the present invention explained above, the content of the average composition of Ce or La in the inclusions where MnS is precipitated is defined.

[0062] Specifically, as explained above, in improving the stretch flange formability and fatigue characteristics, it is important to make MnS precipitate over an oxide or oxysulfide of one or both of Ce or La and prevent stretching of the MnS.

[0063] The form of the inclusions, in the same way as the above, is not particularly limited so long as MnS precipitates on an oxide or oxysulfide of one or both of Ce or La, but in most cases it comprises an oxide or oxysulfide of one or both of Ce or La as a core around which MnS is precipitated.

[0064] Further, the spherical inclusions are not particularly limited, but may be inclusions in the steel plate with a stretch ratio of 3 or less, preferably inclusions with a ratio of 2 or less. Here, if completely spherical, the stretch ratio is 1, so the lower limit of the stretch ratio is 1.

[0065] Therefore, to clarify the composition effective for suppressing stretching of the MnS-based inclusions, the inventors analyzed the composition of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated.

[0066] However, if the circle equivalent diameter of the inclusions is 1 μm or more, observation becomes easy, so for convenience they covered a circle equivalent diameter of 1 μm or more. However, if observation is possible, inclusions with a circle equivalent diameter of less than 1 μm may also be included.

[0067] Further, inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated do not stretch, so it was confirmed that the stretch ratio was 3 or less in all of the inclusions. Therefore, the inventors analyzed the composition of inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 3 or less .

[0068] As a result, they learned that if inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 3 or less contain, in average composition, a total of one or both of Ce or La of 0.5 to 50%, the stretch flange formability and the fatigue characteristics are improved. If the average content of the total of one or both of Ce or La in the inclusions with a circle equivalent diameter of 1 μm or more and a stretch ratio of 3 or less becomes less than 0.5 mass%, the number ratio of the inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated is greatly reduced and, in accordance with this, the number ratio of MnS-based stretched inclusions easily becoming starting points of cracking becomes too large and the stretch flange formability and fatigue characteristics fall.

[0069] On the other hand, if the average content of the total of one or both of Ce or La in the inclusions with a circle equivalent diameter of 1 μm or more and with a stretch ratio of 3 or less exceeds 50%, large amounts of cerium oxysulfides and lanthanum oxysulfides are formed and coarse inclusions with a circle equivalent diameter of 50 μm or so or more are formed, so the stretch flange formability and fatigue characteristics are degraded.

[0070] Further, as a condition of presence of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated in the steel plate of the present invention, the chemical ingredient (Ce+La)/S ratio of the steel plate is defined.

[0071] Specifically, as explained above, in improving the stretch flange formability and fatigue characteristics, the ratio of chemical ingredients for making MnS precipitate on an oxide or oxysulfide of one or both of Ce or La and preventing stretching of the MnS is important.

[0072] Therefore, to clarify the ratio of chemical ingredients effective for suppressing stretching of MnS-based inclusions, the inventors changed the (Ce+La)/S ratio of the steel plate and evaluated the form of the inclusions, stretch flange formability, and fatigue characteristics (FIG. 1). As a result, they learned that when the (Ce+La)/S ratio is 0.1 to 70, the stretch flange formability and the fatigue characteristics are improved. If the (Ce+La)/S ratio becomes less than 0.1, the number ratio of inclusions of a form of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated is greatly reduced, and, in accordance with this, the number ratio of MnS-based stretched inclusions easily becoming starting points of cracking becomes too large and the stretch flange formability and fatigue characteristics fall.

[0073] On the other hand, if the (Ce+La)/S ratio exceeds 70, cerium oxysulfides and lanthanum oxysulfides are formed in large amounts and form coarse inclusions with a circle equivalent diameter of 50 μm or so or more, so the stretch flange formability and the fatigue characteristics are degraded.

[0074] Next, the structure of the steel plate will be explained.

[0075] The present invention improves the stretch flange formability and fatigue characteristics by control of the MnS-based inclusions. The microstructure of the steel plate is not particularly limited. The effect of the present invention is obtained in any steel plate of steel plate of a structure with bainitic ferrite as a main phase, composite structure steel plate having a ferrite phase as a main phase and having a martensite phase or bainite phase as a second phase, and composite structure steel plate comprised of ferrite, residual austenite, and a low temperature transformed phase (martensite or bainite), but to obtain a superior stretch flange formability, making the structure one having bainitic ferrite as its main phase is preferred. Preferably the bainitic ferrite or bainite phase is the largest phase in terms of area ratio. The area rate of the bainitic ferrite phase is preferably 50% or more, more preferably 80% or more, still more preferably 100%. Further, the balance may be made a bainite phase or polygonal ferrite phase contained in an amount of 20% or more.

[0076] Next, the production conditions will be explained. In the present invention, the molten steel is blow refined in a converter to decarburize it and is further decarburized by using a vacuum degassing apparatus to make the C concentration 0.03 to 0.1%. Si, Mn, P, and other alloys are added to this molten steel for deoxidation and adjustment of the ingredients. Along with this either Al and Ti are not added or, when adjustment of the oxygen is necessary, a small amount of Al or Ti of an extent whereby a small amount of acid soluble Al or acid soluble Ti remains is added, then one or both of Ce or La is added to adjust the composition. The thus produced molten steel is continuously cast to produce a cast slab.

[0077] Regarding the continuous casting, not only may the invention be applied to continuous casting of slabs of an extent of the usually 250 mm thickness, but it may also be sufficiently applied to continuous casting of blooms or billets or of thin slabs produced by slab continuous casting machine with thicknesses of the casting molds thinner than usual, for example, 150 mm or less.

[0078] The hot rolling conditions for producing high strength hot rolled steel plate will be explained next. The heating temperature of the slabs before hot rolling is preferably 1150°C or more for making the carbonitrides etc. in the steel enter solid solution. By making these enter solid solution, the formation of polygonal ferrite is suppressed in the cooling process after rolling and a structure mainly comprised of a bainitic ferrite phase preferable for the stretch flange formability is obtained. On the other hand, if the heating temperature of the slab before hot rolling exceeds 1250°C, the oxidation of the slab surface becomes remarkable. In particular, the grain boundaries are selectively oxidized. Due to this, wedge-shaped surface defects remain after descaling. This detracts from the surface quality after rolling, so the upper limit is preferably made 1250°C.

[0079] After heating to the above temperature range, the usual hot rolling is performed, but during this process, the finish rolling end temperature is important when controlling the structure of the steel plate. When the finish rolling end temperature is less than the Ar_3 point+30°C, the crystal grains at the surface layer easily become coarser. This is not preferable for the fatigue characteristics. On the other hand, if over the Ar_3 point+200°C, a polygonal ferrite phase not preferable for the stretch flange formability is easily formed, so the upper limit is preferably made the Ar_3 point+200°C.

[0080] Further, making the average cooling rate of the steel plate after finish rolling 40°C/s or more and cooling in the range up to 300 to 500°C is effective for suppressing the formation of the polygonal ferrite phase and obtaining a structure mainly comprised of a bainitic ferrite phase.

[0081] If the average cooling rate is less than 40°C/s, polygonal ferrite phase forms more easily, so this is not preferred. On the other hand, for control of the structure, it is not necessary to provide an upper limit for the cooling rate, but too fast a cooling rate is liable to make the cooling of the steel plate uneven. Further, construction of a facility enabling such cooling requires tremendous costs. This is believed to invite a rise in the price of steel plate. From such a viewpoint, the upper limit of the cooling rate is preferably made 100°C/s.

[0082] Further, if the cooling stop temperature becomes lower than 300°C, a martensite phase not preferable for stretch flange formability is formed, so the lower limit was made 300°C. Therefore, the coiling temperature of the hot rolled coil is preferably made 300°C or more for suppressing the formation of a martensite phase causing extreme deterioration of the stretch flange formability.

[0083] On the other hand, if over 500°C, formation of a polygonal ferrite phase cannot be suppressed. Further, in steel containing Cu, Cu is liable to locally precipitate in the ferrite phase and lower the effect of improvement of the fatigue characteristics, so the coiling temperature is preferably made 500°C or less. Therefore, by coiling at 500°C or less, carbonitrides are precipitated in the subsequent cooling process so reduce the amounts of solid solution C and N in the ferrite phase and cause an improvement in the stretch flange formability.

EXAMPLES

[0084] Below, examples of the present invention will be explained along with comparative examples.

[0085] Slabs having the chemical ingredients shown in Table 1 were hot rolled under the conditions shown in Table 2 to obtain hot rolled plates of a thickness of 3.2 mm.

Table 1

	Steel No.	C	Si	Mn	P	S	N	Acid sol. Al	Acid sol. Ti	Cr	Nb	V	Mo	B	Cu	Ni	Ce	La	(Ce+La)/S
Inv. Ex. 1	1	0.07	0.20	1.3	0.015	0.0050	0.0025	0.006									0.0010		0.2
Comp. Ex. 1	2	0.07	0.19	1.3	0.015	0.0050	0.0026	0.035											
Inv. Ex. 2	3	0.065	0.18	1.5	0.012	0.0100	0.0022	0.004	0.005		0.02				0.1	0.05	0.0050	0.0030	0.8
Comp. Ex. 2	4	0.065	0.18	1.5	0.012	0.0100	0.0023	0.040	0.005		0.02				0.1	0.05			
Inv. Ex. 3	5	0.095	1.00	2.8	0.010	0.0080	0.0030	0.002	0.002									0.0200	2.5
Comp. Ex. 3	6	0.095	1.00	2.8	0.009	0.0080	0.0028	0.038	0.002										
Inv. Ex. 4	7	0.035	1.00	1.4	0.010	0.0200	0.0020	0.003			0.10						0.0250		1.25
Comp. Ex. 4	8	0.035	1.00	1.39	0.010	0.0200	0.0021	0.003			0.10						0.0003		0.0015
Inv. Ex. 5	9	0.06	0.68	1.38	0.010	0.0040	0.0020	0.003	0.002								0.0070		1.75
Comp. Ex. 5	10	0.06	0.69	1.38	0.010	0.0040	0.0021	0.003	0.002								0.0003		0.075
Inv. Ex. 6	11	0.06	0.68	1.38	0.010	0.0007	0.0020	0.003	0.002								0.0050		7.143
Comp. Ex. 6	12	0.06	0.69	1.38	0.010	0.0007	0.0021	0.003	0.002										
Inv. Ex. 7	13	0.1	0.25	2	0.010	0.0030	0.0020	0.003	0.002	0.03	0.03	0.02	0.15	0.002			0.0050	0.0030	2.667
Comp. Ex. 7	14	0.1	0.25	2	0.010	0.0030	0.0021	0.003	0.002	0.03	0.03	0.02	0.15	0.002			0.0002		0.067

Table 2

Conditions	Heating temperature (°C)	Finish rolling end temperature (°C)	Cooling rate after finish rolling (°C/s)	Coiling temperature (°C)
A	1250	845	75	450
B	1200	825	45	450

[0086] In this Table 1, Steel Numbers (hereinafter referred to as "Steel Nos.") 1, 3, 5, 7, 9, 11, and 13 are made compositions in the range of high strength steel plate according to the present invention, while Steel Nos. 2, 4, 6, 8, 10, 12, and 14 are made comparative steels outside the range of high strength steel plate according to the present invention. Steel Nos. 2, 4, and 6 were made slabs containing acid soluble Al in over 0.01%, while Steel Nos. 8, 10, 12, and 14 were made slabs with the total of one or both of Ce or La reduced to less than 0.0005.

[0087] In this regard, in Table 1, to enable the Steel No. 1 and the Steel No. 2, the Steel No. 3 and the Steel No. 4, the Steel No. 5 and the Steel No. 6, and the Steel No. 7 and the Steel No. 8 to be compared, they were made substantially the same in composition and made different in acid soluble Al etc. Further, to enable the Steel No. 9 and Steel No. 10, the Steel No. 11 and Steel No. 12, and the Steel No. 13 and Steel No. 14 to be compared, they were made substantially the same in composition and made different in Ce+La etc.

[0088] Further, in this Table 2, the Conditions A were made a heating temperature of 1250°C, a finish rolling end temperature of 845°C, a cooling rate after finish rolling of 75°C/s, and a coiling temperature of 450°C, while the Conditions B were made a heating temperature of 1200°C, a finish rolling end temperature of 825°C, a cooling rate after finish rolling of 45°C/s, and a coiling temperature of 450°C.

[0089] For the Steel No. 1 and the Steel No. 2, the Conditions A were applied, further for the Steel No. 3 and the Steel No. 4, the Conditions B were applied, for the Steel No. 5 and the Steel No. 6, the Conditions A were applied, and for the Steel No. 7 and the Steel No. 8, the Steel No. 9 and the Steel No. 10, the Steel No. 11 and the Steel No. 12, and the Steel No. 13 and the Steel No. 14, the Conditions B were applied to enable the effects of the chemical compositions to be compared under the same production conditions.

[0090] As basic characteristics of the steel plates obtained in this way, the inventors investigated the strength, ductility, stretch flange formability, and fatigue strength ratio.

[0091] Further, as the state of presence of stretched inclusions in the steel plate, the inventors investigated the number ratio, volume number density, and average circle equivalent diameter of inclusions having a stretch ratio of 5 or more for all inclusions of 1 μm or more.

[0092] Furthermore, as the state of presence of unstretched inclusions in the steel plate, the inventors investigated the number ratio and volume number density of inclusions comprised of an oxide or oxysulfide of one or both of Ce or La on which MnS has precipitated for all inclusions of 1 μm or more and the average value of contents of the total of one or both of Ce or La in the inclusions with a stretch ratio of 3 or less.

[0093] Note that inclusions of 1 μm or more were covered because of the ease of observation and, in addition, the fact that inclusions of less than 1 μm do not have any effect on deterioration of the stretch flange formability and fatigue characteristics.

[0094] The results are shown in Table 3 for each combination of steel and rolling conditions.

Table 3

Condition	Strength	Ductility	Ce+MnS number ratio	Stretched number ratio	Ce+MnS volume number density	Stretched volume number density	Average content of total of one or both of Ce or La in inclusions with circle equivalent diameter 1 μm or more and stretch ratio 3 or less (%)	Average circle equivalent diameter in inclusions with circle equivalent diameter 1 μm or more and stretch ratio 5 or more (μm)	Hole expansion value	Fatigue strength ratio
A	460	23	90	0	2.5×10^4	0	2	6	160	0.67
A	458	20	0	75	0	2.8×10^4	0	12	110	0.48
B	497	22	80	5	6.1×10^4	4.1×10^3	10	7	162	0.6
B	495	19	0	85	0	7.0×10^4	0	22	105	0.46
A	1150	11	85	0	2.8×10^4	0	30	5	80	0.64
A	1140	8	0	80	0	4.7×10^4	0	18	45	0.45
B	810	22	87	7	9.6×10^4	7.2×10^3	33	9	100	0.61
B	805	20	1	97	9.6×10^2	9.3×10^4	0.4	24	62	0.44
B	605	25	83	6	8.8×10^4	6.1×10^3	29	8	90	0.68
B	605	25	1	95	8.4×10^2	9.3×10^4	0.4	23	38	0.49
B	605	25	87	0	9.5×10^4	0	50	5	100	0.68
B	605	25	0	97	0	9.4×10^4	0	23	34	0.49
B	1005	17	86	5	9.7×10^4	5.9×10^3	34	7	75	0.63
B	995	16	1	96	8.2×10^2	9.4×10^4	0.3	24	30	0.44

[0095] The strength and ductility were found by a tensile test of a JIS No. 5 test piece taken in parallel with the rolling direction. The stretch flange formability was evaluated by pushing open a punched hole of a diameter of 10 mm made at the center of a 150 mm×150 mm steel plate by a 60° conical punch, measuring the hole diameter D (mm) when a crack occurs passing through the plate thickness, and finding the hole expansion value λ=(D-10)/10. Further, the fatigue strength ratio used as an indicator showing the fatigue characteristics was evaluated by the value of the fatigue strength at 2×10^6 cycles (σN) found by the method based on JIS Z 2275 divided by the strength (σB) of the steel plate (σW/σB).

[0096] Note that the test piece used was a No. 1 test piece defined in the specification having a parallel part of 25 mm, a radius of curvature R of 100 mm, and a thickness after equally grinding the two surfaces of the original plate (hot rolled plate) of 3.0 mm.

[0097] Furthermore, the inclusions were observed under a SEM. Fifty randomly selected inclusions with a circle equivalent diameter of 1 μm or more were measured for their long axes and short axes. Furthermore, the quantitative analysis function of an SEM was used to analyze the composition of 50 randomly selected inclusions with a circle equivalent diameter of 1 μm or more. Using these results, the number ratio of inclusions with a stretch ratio of 5 or more, the average circle equivalent diameter of inclusions with a stretch ratio of 5 or more, the number ratio of inclusions comprised of an oxide or oxysulfide of one or both of Ce or La on which MnS has precipitated, and furthermore an average value of the total of one or both of Ce or La in the inclusions with a stretch ratio of 3 or less were found. Further, the volume number density by type of inclusions was calculated by evaluation of the electrolyzed surface by SEM evaluation by the speed method.

[0098] As clear from Table 3, in Steel Nos. 1, 3, 5, 7, 9, 11, and 13 applying the method of the present invention, by making MnS precipitate at an oxide or oxysulfide of one or both of Ce or La, it was possible to reduce the stretched MnS-based inclusions in the steel plate. That is, by making the number ratio of inclusions comprised of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated in the steel plate 10% or more, making the volume number density of the inclusions 1.0×10^3/mm^3 or more, and making the average content of the total of one or both of Ce or La in the inclusions with a stretch ratio of 3 or less present in the steel plate 0.5% to 50%, it was possible to make the number ratio of the stretched inclusions with a circle equivalent diameter 1 μm or more and with a stretch ratio of 5 or more 200 or less, make the volume number density of the inclusions 1.0×10^4/mm^3 or less, and make the overage circle equivalent diameter of the inclusions 10 μm or less. As a result, compared with the comparative steels, in the invention steels of Steel Nos. 1, 3, 5, 7, 9, 11, and 13, steel plate superior in stretch flange formability and fatigue characteristics could be obtained. However, in the comparative steels (Steel Nos. 2, 4, 6, 8, 10, 12, and 14), the state of distribution of the stretched MnS-based inclusions and inclusions comprised of an oxide or oxysulfide of one or both of Ce or La at which MnS has been precipitated differs from the state of distribution prescribed in the present invention, so at the time of working the steel plate, the stretched MnS-based inclusions formed starting points of cracking and the stretch flange formability and the fatigue characteristics dropped.

INDUSTRIAL APPLICABILITY

[0099] According to the method of the present invention, by masking fine MnS precipitate in the slab and making them disperse in the steel plate as fine spherical inclusions not being deformed at the time of rolling and not easily forming starting points of cracking, high strength hot rolled steel plate superior in stretch flange formability and fatigue characteristics can be obtained.

Claims

1. A high strength steel plate superior in stretch flange formability and fatigue characteristics **characterized by** comprising steel plate containing, by mass%,
C: 0.03 to 0.20%,
Si: 0.08 to 1.5%,
Mn: 1.0 to 3.0%,
P: 0.05% or less,
S: 0.0005% or more,
N: 0.0005 to 0.01%,
acid soluble Al: 0.01% or less,
acid soluble Ti: less than 0.008%, and
a total of one or both of Ce or La: 0.0005 to 0.04%,
having a balance of iron and unavoidable impurities, and
having a number ratio of 20% or less of stretched inclusions present in the steel plate having a circle equivalent diameter of 1 μm or more and a long axis/short axis of 5 or more.

2. A high strength steel plate superior in stretch flange formability and fatigue characteristics **characterized by** comprising steel plate containing, by mass%,
C: 0.03 to 0.20%,
Si: 0.08 to 1.5%,
Mn: 1.0 to 3.0%,
P: 0.05% or less,
S: 0.0005% or more,
N: 0.0005 to 0.01%,
acid soluble Al: 0.01% or less,
acid soluble Ti: less than 0.008%, and
a total of one or both of Ce or La: 0.0005 to 0.04%,
having a balance of iron and unavoidable impurities,
and having inclusions in the steel plate comprised of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated in a number ratio of 10% or more.

3. A high strength steel plate superior in stretch flange formability and fatigue characteristics **characterized by** comprising steel plate containing, by mass%,
C: 0.03 to 0.20%,
Si: 0.08 to 1.5%,
Mn: 1.0 to 3.0%,
P: 0.05% or less,
S: 0.0005% or more,
N: 0.0005 to 0.01%,
acid soluble Al: 0.01% or less,
acid soluble Ti: less than 0.008%, and
a total of one or both of Ce or La: 0.0005 to 0.04%,
having a balance of iron and unavoidable impurities, and
having a volume number ratio of $1.0\times10^4/mm^3$ or less of stretched inclusions present in the steel plate having a circle equivalent diameter of 1 μm or more and a long axis/short axis of 5 or more.

4. A high strength steel plate superior in stretch flange formability and fatigue characteristics **characterized by** comprising steel plate containing, by mass%,
C: 0.03 to 0.20%,
Si: 0.08 to 1.5%,
Mn: 1.0 to 3.0%,
P: 0.05% or less,
S: 0.0005% or more,
N: 0.0005 to 0.01%,
acid soluble Al: 0.01% or less,
acid soluble Ti: less than 0.008%, and
a total of one or both of Ce or La: 0.0005 to 0.04%,
having a balance of iron and unavoidable impurities, and
having a volume number density of inclusions in the steel plate comprised of an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated in a volume number density of $1.0\times10^3/mm^3$ or more.

5. A high strength steel plate superior in stretch flange formability and fatigue characteristics **characterized by** comprising steel plate containing, by mass%,
C: 0.03 to 0.20%,
Si: 0.08 to 1.5%,
Mn: 1.0 to 3.0%,
P: 0.05% or less,
S: 0.0005% or more,
N: 0.0005 to 0.01%,
acid soluble Al: 0.01% or less,
acid soluble Ti: less than 0.008%, and
a total of one or both of Ce or La: 0.0005 to 0.04%,
having a balance of iron and unavoidable impurities, and
having an average circle equivalent diameter of 10 μm or less of stretched inclusions present in the steel plate

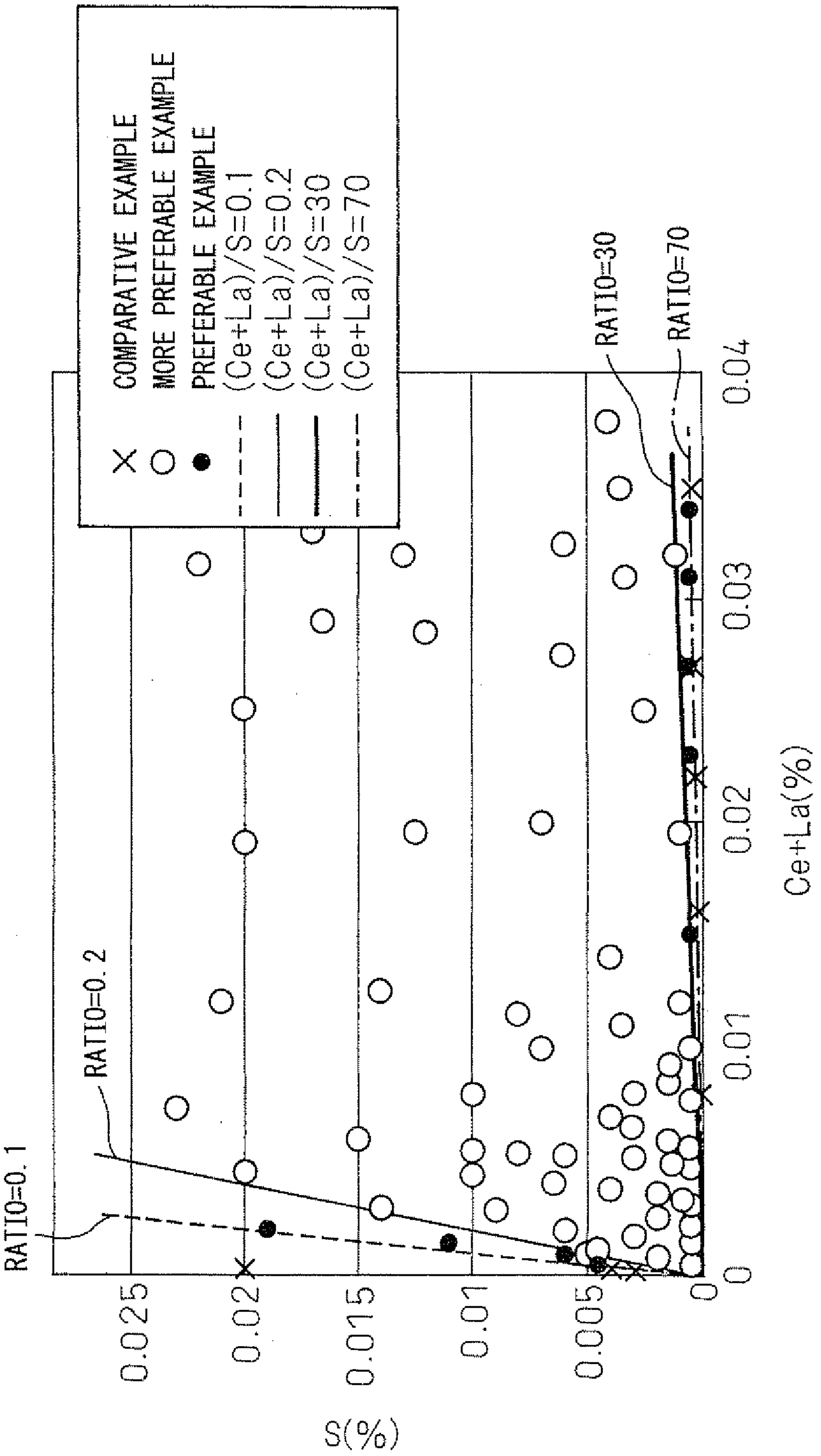
having a circle equivalent diameter of 1 μm or more and a long axis/short axis of 5 or more.

6. A high strength steel plate superior in stretch flange formability and fatigue characteristics **characterized by** comprising steel plate containing, by mass%,
C: 0.03 to 0.20%,
Si: 0.08 to 1.5%,
Mn: 1.0 to 3.0%,
P: 0.05% or less,
S: 0.0005% or more,
N: 0.0005 to 0.01%,
acid soluble Al: 0.01% or less,
acid soluble Ti: less than 0.008%, and
a total of one or both of Ce or La: 0.0005 to 0.04%,
having a balance of iron and unavoidable impurities,
having inclusions present in the steel plate comprising an oxide or oxysulfide of one or both of Ce or La on which MnS is precipitated, and having the inclusions include, in average composition, a total of one or both of Ce or La in 0.5 to 50 mass%.

7. A high strength steel plate superior in stretch flange formability and fatigue characteristics **characterized by** comprising steel plate containing, by mass%,
C: 0.03 to 0.20%,
Si: 0.08 to 1.5%,
Mn: 1.0 to 3.0%,
P: 0.05% or less,
S: 0.0005% or more,
N: 0.0005 to 0.01%,
acid soluble Al: 0.01% or less,
acid soluble Ti: less than 0.008%, and
a total of one or both of Ce or La: 0.0005 to 0.04%,
having a balance of iron and unavoidable impurities, and
having a (Ce+La)/S ratio of 0.1 to 70.

8. A high strength steel plate superior in stretch flange formability and fatigue characteristics as set forth in any one of claims 1 to 7 **characterized by** comprising steel plate containing, by mass%, one or more of any of
Nb: 0.01 to 0.10%,
V: 0.01 to 0.05%,
Cr: 0.01 to 0.6%,
Mo: 0.01 to 0.4%, and
B: 0.0003 to 0.03% and
having a balance of iron and unavoidable impurities.

Fig.1


COMPARATIVE EXAMPLE
MORE PREFERABLE EXAMPLE
PREFERABLE EXAMPLE
(Ce+La)/S=0.1
(Ce+La)/S=0.2
(Ce+La)/S=30
(Ce+La)/S=70
RATIO=0.1
RATIO=0.2
RATIO=30
RATIO=70
S(%)
0.025
0.02
0.015
0.01
0.005
0
0.01
0.02
0.03
0.04
Ce+La(%)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/054614

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C22C38/14*(2006.01)i, *C22C38/38*(2006.01)i, *C21D9/46* (2006.01)n

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, 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	1996-2007
Kokai Jitsuyo Shinan Koho	1971-2007	Toroku Jitsuyo Shinan Koho	1994-2007

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2006-70302 A (Nippon Steel Corp.), 16 March, 2006 (16.03.06), Par. Nos. [0045] to [0056]; Steel No. 2 (Family: none)	8
X	JP 2005-307301 A (Nippon Steel Corp.), 04 November, 2005 (04.11.05), Par. Nos. [0004], [0050]; examples; Steel No. 3-1 (Family: none)	1-8
X	JP 2004-256906 A (Nippon Steel Corp.), 16 September, 2004 (16.09.04), Examples (K-2) (Family: none)	1-8

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 June, 2007 (05.06.07)	19 June, 2007 (19.06.07)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/054614

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2003-171734 A (Nippon Steel Corp.), 20 June, 2003 (20.06.03), (Family: none)	1-8
A	JP 2004-315902 A (Nippon Steel Corp.), 11 November, 2004 (11.11.04), (Family: none)	1-8
A	JP 2005-256115 A (Nippon Steel Corp.), 22 September, 2005 (22.09.05), (Family: none)	1-8

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 11199973 A **[0004] [0004]**
- JP 2001200331 A **[0006] [0006] [0007]**