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(54) **HIGH-STRENGTH STEEL SHEET AND MANUFACTURING METHOD THEREFOR**

(57) Objects are to provide a high strength steel sheet having a TS of 1320 MPa or more and a YR of 85% or more and having a wide range of appropriate clearances not leading to delayed fracture; and to provide a method for manufacturing the same.

A high strength steel sheet includes a specific microstructure having a specific chemical composition and satisfying the formulas (1) and (2) defined below:

$$KAM (S)/KAM (C) < 1.00 \cdots \cdots (1)$$

wherein KAM (S) is a KAM (Kernel average misorientation) value of a superficial portion of the steel sheet, and KAM (C) is a KAM value of a central portion of the steel sheet,

$$Hv (Q) - Hv (S) \geq 8 \cdots \cdots (2)$$

wherein Hv (Q) indicates the hardness of a portion at 1/4 sheet thickness and Hv (S) indicates the hardness of a superficial portion of the steel sheet.

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Description

Technical Field

5 **[0001]** The present invention relates to a high strength steel sheet excellent in tensile strength and delayed fracture resistance, and to a method for manufacturing the same. The high strength steel sheet of the present invention may be suitably used as structural members, such as automobile parts.

Background Art

10 **[0002]** Steel sheets for automobiles are being increased in strength to reduce CO₂ emissions by weight reduction of vehicles and to enhance crashworthiness by weight reduction of automobile bodies at the same time, with introduction of new laws and regulations one after another. To increase the strength of automobile bodies, high strength steel sheets having a tensile strength (TS) of 1320 MPa or higher class are increasingly applied to principal structural parts of automobiles.

15 **[0003]** High strength steel sheets used for automobiles are required to have an excellent yield ratio (YR = yield strength YS/tensile strength TS) from the point of view of performance of parts. For example, automobile frame parts, such as bumpers, are required to exhibit excellent impact absorption at the time of collision. Thus, steel sheets that have excellent YR correlated with impact absorption are favorably used.

20 **[0004]** Automobile frame parts have many end faces formed by shearing. The morphology of a sheared end face depends on the shear clearance. The morphology of a sheared end face affects delayed fracture resistance. Here, delayed fracture is a phenomenon in which, when a formed part is placed in a hydrogen penetration environment, hydrogen penetrates into the steel sheet constituting the part to cause a decrease in interatomic bonding force or to cause local deformation, thus giving rise to microcracks that grow to fracture. High strength steel sheets used for automobiles are required to have a wide range of appropriate clearances not leading to delayed fracture.

25 **[0005]** To cope with these demands, for example, Patent Literature 1 provides a high strength steel sheet having a tensile strength of 980 MPa or more and excellent bending formability, and a method for manufacturing the same. However, the technique described in Patent Literature 1 does not consider YR or the range of appropriate clearances not leading to delayed fracture. Furthermore, the steel sheets described in Patent Literature 1 do not achieve YR ≥ 85%.

30 **[0006]** For example, Patent Literature 2 provides a high strength steel sheet having a tensile strength of 1320 MPa or more and excellent delayed fracture resistance at sheared end faces, and a method for manufacturing the same. However, the technique described in Patent Literature 2 does not consider the range of appropriate clearances not leading to delayed fracture.

35 **[0007]** For example, Patent Literature 3 provides a high strength steel sheet having a tensile strength of 1100 MPa or more and being excellent in YR, surface quality, and weldability, and a method for manufacturing the same. However, the technique described in Patent Literature 3 does not consider the range of appropriate clearances not leading to delayed fracture.

Citation List

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Patent Literature

[0008]

45 PTL 1: Japanese Patent No. 6354909
PTL 2: Japanese Patent No. 6112261
PTL 3: Japanese Patent No. 6525114

Summary of Invention

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Technical Problem

[0009] The present invention has been developed in view of the circumstances discussed above. Objects of the present invention are therefore to provide a high strength steel sheet having a TS of 1320 MPa or more and a YR of 85% or more and having a wide range of appropriate clearances not leading to delayed fracture; and to provide a method for manufacturing the same.

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Solution to Problem

[0010] The present inventors carried out extensive studies directed to solving the problems described above and have consequently found the following facts.

- (1) 1320 MPa or higher TS can be achieved by limiting tempered martensite to 85% or more.
- (2) 85% or higher YR can be achieved by limiting retained austenite to less than 5%, KAM (S)/KAM (C) to less than 1.00, and further Hv (Q) - Hv (S) to 8 or more.
- (3) A wide range of appropriate clearances not leading to delayed fracture can be achieved by limiting KAM (S)/KAM (C) to less than 1.00 and further Hv (Q) - Hv (S) to 8 or more.

[0011] The present invention has been made based on the above findings. Specifically, a summary of configurations of the present invention is as follows.

[1] A high strength steel sheet including a microstructure having a chemical composition including, by mass%:

C: 0.15% or more and 0.45% or less,
 Si: 0.10% or more and 2.00% or less,
 Mn: 0.5% or more and 3.5% or less,
 P: 0.100% or less,
 S: 0.0200% or less,
 Al: 0.010% or more and 1.000% or less,
 N: 0.0100% or less, and
 H: 0.0020% or less,
 the balance being Fe and incidental impurities;
 the microstructure being such that:

the area fraction of tempered martensite is 85% or more,
 the volume fraction of retained austenite is less than 5%, and
 the area fraction of the total of ferrite and bainitic ferrite is 10% or less;
 the microstructure satisfying the formulas (1) and (2) defined below:

$$\text{KAM (S) / KAM (C)} < 1.00 \quad \dots \dots (1)$$

wherein KAM (S) is a KAM (Kernel average misorientation) value of a superficial portion of the steel sheet, and KAM (C) is a KAM value of a central portion of the steel sheet,

$$\text{Hv (Q)} - \text{Hv (S)} \geq 8 \quad \dots \dots (2)$$

wherein Hv (Q) indicates the hardness of a portion at 1/4 sheet thickness and Hv (S) indicates the hardness of a superficial portion of the steel sheet.

[2] The high strength steel sheet described in [1], wherein the chemical composition further includes one, or two or more elements selected from, by mass%:

Ti: 0.100% or less,
 B: 0.0100% or less,
 Nb: 0.100% or less,
 Cu: 1.00% or less,
 Cr: 1.00% or less,
 V: 0.100% or less,
 Mo: 0.500% or less,
 Ni: 0.50% or less,
 Sb: 0.200% or less,
 Sn: 0.200% or less,
 As: 0.100% or less,

Ta: 0.100% or less,
 Ca: 0.0200% or less,
 Mg: 0.0200% or less,
 Zn: 0.020% or less,
 Co: 0.020% or less,
 Zr: 0.020% or less, and
 REM: 0.0200% or less.

[3] The high strength steel sheet described in [1] or [2], which has a coated layer on a surface of the steel sheet.

[4] A method for manufacturing a high strength steel sheet described in [1] or [2], the method including:

providing a cold rolled steel sheet produced by subjecting a steel slab to hot rolling, pickling, and cold rolling;
 annealing the steel sheet under conditions where:

a temperature T1 is 850°C or above and 1000°C or below and
 a holding time t1 at T1 is 10 seconds or more and 1000 seconds or less;
 cooling the steel sheet to 100°C or below;
 starting working at an elapsed time t2 of 1000 seconds or less from the time when the temperature reaches
 100°C, the working being performed under conditions where:

a working start temperature T2 is 80°C or below and an equivalent plastic strain is 0.10% or more and
 5.00% or less;
 tempering the steel sheet under conditions where:

a temperature T3 is 100°C or above and 400°C or below and
 a holding time t3 at T3 is 1.0 second or more and 1000.0 seconds or less; and
 cooling the steel sheet under conditions where a cooling rate θ_1 from T3 to 80°C is 100°C/sec or less.

[5] The method for manufacturing a high strength steel sheet described in [4], wherein the working before the
 tempering is performed under conditions where strain is applied by two or more separate working operations, and
 the total of the equivalent plastic strains applied in the working operations is 0.10% or more.

[6] The method for manufacturing a high strength steel sheet described in [4] or [5], further including performing
 coating treatment during the annealing or after the annealing.

Advantageous Effects of Invention

[0012] According to the present invention, a high strength steel sheet can be obtained that has a TS of 1320 MPa or
 more and a YR of 85% or more and has a wide range of appropriate clearances not leading to delayed fracture. Fur-
 thermore, for example, the high strength steel sheet of the present invention may be applied to automobile structural
 members to reduce the weight of automobile bodies and thereby to enhance fuel efficiency. Thus, the present invention
 is highly valuable in industry.

Description of Embodiments

[0013] Embodiments of the present invention will be described below.

[0014] First, appropriate ranges of the chemical composition of the high strength steel sheet and the reasons why the
 chemical composition is thus limited will be described. In the following description, "%" indicating the contents of con-
 stituent elements of steel means "mass%" unless otherwise specified.

C: 0.15% or more and 0.45% or less

[0015] Carbon is one of the important basic components of steel, and, particularly in the present invention, is an
 important element that affects TS. If the C content is less than 0.15%, it is difficult to achieve 1320 MPa or higher TS.
 Thus, the C content is limited to 0.15% or more. The C content is preferably 0.16% or more. The C content is more
 preferably 0.17% or more. The C content is still more preferably 0.18% or more. The C content is most preferably 0.19%
 or more. However, if the C content is more than 0.45%, the ultimate deformability of the steel is lowered and the range
 of appropriate clearances not leading to delayed fracture is narrowed. Thus, the C content is limited to 0.45% or less.
 The C content is preferably 0.40% or less. The C content is more preferably 0.35% or less. The C content is still more

preferably 0.30% or less. The C content is most preferably 0.26% or less.

Si: 0.10% or more and 2.00% or less

5 **[0016]** Silicon is one of the important basic components of steel, and, particularly in the present invention, is an important element that affects TS and retained austenite. If the Si content is less than 0.10%, 1320 MPa or higher TS is hardly achieved. Thus, the Si content is limited to 0.10% or more. The Si content is preferably 0.15% or more. The Si content is more preferably 0.20% or more. The Si content is still more preferably 0.30% or more. The Si content is most preferably 0.40% or more. However, if the Si content is more than 2.00%, the amount of retained austenite excessively
10 increases to make it difficult to achieve 85% or higher YR. Thus, the Si content is limited to 2.00% or less. The Si content is preferably 1.80% or less. The Si content is more preferably 1.60% or less. The Si content is still more preferably 1.50% or less. The Si content is most preferably 1.20% or less.

Mn: 0.5% or more and 3.5% or less

15 **[0017]** Manganese is one of the important basic components of steel, and, particularly in the present invention, is an important element that affects the fraction of ferrite and the fraction of bainite. If the Mn content is less than 0.5%, the fraction of ferrite and the fraction of bainite are increased to make it difficult to achieve 1320 MPa or higher TS and to achieve 85% or higher YR. Thus, the Mn content is limited to 0.5% or more. The Mn content is preferably 0.7% or more.
20 The Mn content is more preferably 1.0% or more. The Mn content is still more preferably 1.1% or more. The Mn content is most preferably 1.5% or more. However, if the Mn content is more than 3.5%, manganese macro-segregation occurs to lower the ultimate deformability of the steel and thereby to narrow the range of appropriate clearances not leading to delayed fracture. Thus, the Mn content is limited to 3.5% or less. The Mn content is preferably 3.3% or less. The Mn content is more preferably 3.1% or less. The Mn content is still more preferably 3.0% or less. The Mn content is most
25 preferably 2.8% or less.

P: 0.100% or less

30 **[0018]** If the P content is more than 0.100%, phosphorus is segregated at grain boundaries to make the steel sheet brittle and to narrow the range of appropriate clearances not leading to delayed fracture. Thus, the P content is limited to 0.100% or less. The P content is preferably 0.080% or less. The P content is more preferably 0.060% or less. The lower limit of the P content is not particularly limited but is preferably 0.001% or more due to production technology limitations.

35 S: 0.0200% or less

[0019] If the S content is more than 0.0200%, sulfides are formed making the ultimate deformability of the steel lower and thereby narrow the range of appropriate clearances not leading to delayed fracture. Thus, the S content is limited to 0.0200% or less. The S content is preferably 0.0100% or less. The S content is more preferably 0.0050% or less. The
40 lower limit of the S content is not particularly limited but is preferably 0.0001% or more due to production technology limitations.

Al: 0.010% or more and 1.000% or less

45 **[0020]** The addition of aluminum increases the strength of the steel sheet and facilitates achieving 1320 MPa or higher TS. To obtain these effects, the Al content needs to be 0.010% or more. Thus, the Al content is limited to 0.010% or more. The Al content is preferably 0.012% or more. The Al content is more preferably 0.015% or more. The Al content is still more preferably 0.020% or more. However, if the Al content is more than 1.000%, the fraction of ferrite and the fraction of bainite increase to make it difficult to achieve 1320 MPa or higher TS and to achieve 85% or higher YR. Thus,
50 the Al content is limited to 1.000% or less. The Al content is preferably 0.500% or less. The Al content is more preferably 0.100% or less.

N: 0.0100% or less

55 **[0021]** If the N content is more than 0.0100%, the cast slab becomes brittle and is easily cracked to cause a significant decrease in productivity. Thus, the N content is limited to 0.0100% or less. The N content is preferably 0.0080% or less. The N content is more preferably 0.0070% or less. The N content is still more preferably 0.0060% or less. The N content is most preferably 0.0050% or less. The lower limit of the N content is not particularly limited but is preferably 0.0010%

or more due to production technology limitations.

H: 0.0020% or less

5 **[0022]** If the H content exceeds not more than 0.0020%, the ultimate deformability of the steel is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the H content is limited to 0.0020% or less. The H content is preferably 0.0015% or less. The H content is more preferably 0.0010% or less. The lower limit of the H content is not particularly limited. The H content may be 0% because the lower the H content, the wider the range of appropriate clearances not leading to delayed fracture.

10 **[0023]** In addition to the chemical composition described above, the high strength steel sheet of the present invention preferably further contains one, or two or more elements selected from, by mass%, Ti: 0.100% or less, B: 0.0100% or less, Nb: 0.100% or less, Cu: 1.00% or less, Cr: 1.00% or less, V: 0.100% or less, Mo: 0.500% or less, Ni: 0.50% or less, Sb: 0.200% or less, Sn: 0.200% or less, As: 0.100% or less, Ta: 0.100% or less, Ca: 0.0200% or less, Mg: 0.0200% or less, Zn: 0.020% or less, Co: 0.020% or less, Zr: 0.020% or less, and REM: 0.0200% or less.

15 Ti: 0.100% or less

[0024] If the Ti content is more than 0.100%, the cast slab becomes brittle and is easily cracked to cause a significant decrease in productivity. Thus, when titanium is added, the content thereof is limited to 0.100% or less. The Ti content is preferably 0.075% or less. The Ti content is more preferably 0.050% or less. The Ti content is still more preferably less than 0.050%. In contrast, the addition of titanium increases the strength of the steel sheet and facilitates achieving 1320 MPa or higher TS. To obtain these effects, the Ti content is preferably 0.001% or more. The Ti content is more preferably 0.005% or more. The Ti content is still more preferably 0.010% or more.

25 B: 0.0100% or less

[0025] If the B content is more than 0.0100%, the cast slab becomes brittle and is easily cracked to cause a significant decrease in productivity. Thus, when boron is added, the content thereof is limited to 0.0100% or less. The B content is preferably 0.0080% or less. The B content is more preferably 0.0050% or less. In contrast, the addition of boron increases the strength of the steel sheet and facilitates achieving 1320 MPa or higher TS. To obtain these effects, the B content is preferably 0.0001% or more. The B content is more preferably 0.0002% or more.

Nb: 0.100% or less

35 **[0026]** If the Nb content is more than 0.100%, the cast slab becomes brittle and is easily cracked to cause a significant decrease in productivity. Thus, when niobium is added, the content thereof is limited to 0.100% or less. The Nb content is preferably 0.090% or less. The Nb content is more preferably 0.050% or less. The Nb content is still more preferably 0.030% or less. In contrast, the addition of niobium increases the strength of the steel sheet and facilitates achieving 1320 MPa or higher TS. To obtain these effects, the Nb content is preferably 0.001% or more. The Nb content is more preferably 0.002% or more.

Cu: 1.00% or less

45 **[0027]** If the Cu content is more than 1.00%, the cast slab becomes brittle and is easily cracked to cause a significant decrease in productivity. Thus, when copper is added, the Cu content is limited to 1.00% or less. The Cu content is preferably 0.50% or less. In contrast, copper suppresses the penetration of hydrogen into the steel sheet and improves the range of appropriate clearances not leading to delayed fracture. To obtain these effects, the Cu content is preferably 0.01% or more. The Cu content is preferably 0.03% or more. The Cu content is more preferably 0.10% or more.

50 Cr: 1.00% or less

[0028] If the Cr content is more than 1.00%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when chromium is added, the content thereof is limited to 1.00% or less. The Cr content is preferably 0.70% or less. The Cr content is more preferably 0.50% or less. In contrast, chromium not only serves as a solid solution strengthening element but also can stabilize austenite and suppress ferrite formation in the cooling process during continuous annealing, thus increasing the strength of the steel sheet. To obtain these effects, the Cr content is preferably 0.01% or more. The Cr content is more preferably 0.02% or more.

V: 0.100% or less

[0029] If the V content is more than 0.100%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when vanadium is added, the content thereof is limited to 0.100% or less. The V content is preferably 0.060% or less. In contrast, vanadium increases the strength of the steel sheet. To obtain this effect, the V content is preferably 0.001% or more. The V content is more preferably 0.005% or more. The V content is still more preferably 0.010% or more.

Mo: 0.500% or less

[0030] If the Mo content is more than 0.500%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when molybdenum is added, the content thereof is limited to 0.500% or less. The Mo content is preferably 0.450% or less. The Mo content is more preferably 0.400% or less. In contrast, molybdenum not only serves as a solid solution strengthening element but also can stabilize austenite and suppress ferrite formation in the cooling process during continuous annealing, thus increasing the strength of the steel sheet. To obtain these effects, the Mo content is preferably 0.010% or more. The Mo content is more preferably 0.020% or more.

Ni: 0.50% or less

[0031] If the Ni content is more than 0.50%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when nickel is added, the content thereof is limited to 0.50% or less. The Ni content is preferably 0.45% or less. The Ni content is more preferably 0.30% or less. In contrast, nickel can stabilize austenite and suppress ferrite formation in the cooling process during continuous annealing, thus increasing the strength of the steel sheet. To obtain these effects, the Ni content is preferably 0.01% or more. The Ni content is more preferably 0.02% or more.

Sb: 0.200% or less

[0032] If the Sb content is more than 0.200%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when antimony is added, the content thereof is limited to 0.200% or less. The Sb content is preferably 0.100% or less. The Sb content is more preferably 0.050% or less. In contrast, antimony suppresses the formation of a soft superficial layer and increases the strength of the steel sheet. To obtain these effects, the Sb content is preferably 0.001% or more. The Sb content is more preferably 0.005% or more.

Sn: 0.200% or less

[0033] If the Sn content is more than 0.200%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when tin is added, the content thereof is limited to 0.200% or less. The Sn content is preferably 0.100% or less. The Sn content is more preferably 0.050% or less. In contrast, tin suppresses the formation of a soft superficial layer and increases the strength of the steel sheet. To obtain these effects, the Sn content is preferably 0.001% or more. The Sn content is more preferably 0.005% or more.

As: 0.100% or less

[0034] If the As content is more than 0.100%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when arsenic is added, the content thereof is limited to 0.100% or less. The As content is preferably 0.060% or less. The As content is more preferably 0.010% or less. Arsenic increases the strength of the steel sheet. To obtain this effect, the As content is preferably 0.001% or more. The As content is more preferably 0.005% or more.

Ta: 0.100% or less

[0035] If the Ta content is more than 0.100%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when tantalum is added, the content thereof is limited to 0.100% or less. The Ta content is preferably 0.050% or

less. The Ta content is more preferably 0.010% or less. On the other hand, tantalum increases the strength of the steel sheet. To obtain this effect, the Ta content is preferably 0.001% or more. The Ta content is more preferably 0.005% or more.

5 Ca: 0.0200% or less

[0036] If the Ca content is more than 0.0200%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when calcium is added, the content thereof is limited to 0.0200% or less. The Ca content is preferably 10 0.0100% or less. In contrast, calcium is an element used for deoxidation, and furthermore this element is effective for controlling the shape of sulfides to spherical, enhancing the ultimate deformability of the steel sheet, and enhancing the range of appropriate clearances not leading to delayed fracture. To obtain these effects, the Ca content is preferably 0.0001% or more.

15 Mg: 0.0200% or less

[0037] If the Mg content is more than 0.0200%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when magnesium is added, the content thereof is limited to 0.0200% or less. In contrast, magnesium 20 is an element used for deoxidation, and furthermore this element is effective for controlling the shape of sulfides to spherical, enhancing the ultimate deformability of the steel sheet, and enhancing the range of appropriate clearances not leading to delayed fracture. To obtain these effects, the Mg content is preferably 0.0001% or more.

Zn: 0.020% or less, Co: 0.020% or less, Zr: 0.020% or less

25 **[0038]** If the contents of zinc, cobalt, and zirconium are each more than 0.020%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when zinc, cobalt, and zirconium are added, the contents thereof are each limited to 0.020% or less. In contrast, zinc, cobalt, and zirconium are elements effective for controlling the shape 30 of inclusions to spherical, enhancing the ultimate deformability of the steel sheet, and enhancing the range of appropriate clearances not leading to delayed fracture. To obtain these effects, the contents of zinc, cobalt, and zirconium are preferably each 0.0001% or more.

REM: 0.0200% or less

35 **[0039]** If the REM content is more than 0.0200%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when rare earth metals are added, the content thereof is limited to 0.0200% or less. In contrast, rare earth metals are elements effective for controlling the shape of inclusions to spherical, enhancing the ultimate deformability 40 of the steel sheet, and enhancing the range of appropriate clearances not leading to delayed fracture. To obtain these effects, the REM content is preferably 0.0001% or more.

[0040] The balance of the composition is Fe and incidental impurities. When the content of any of the above optional elements is below the lower limit, the element does not impair the advantageous effects of the present invention. Thus, such an optional element below the lower limit content is regarded as an incidental impurity.

45 **[0041]** Next, the steel microstructure of the high strength steel sheet of the present invention will be described.

Tempered martensite: 85% or more in terms of area fraction

[0042] This requirement is a highly important claim component in the present invention. 1320 MPa or higher TS may be achieved by making martensite as the main phase. To obtain this effect, the area fraction of tempered martensite 50 needs to be 85% or more. Thus, the area fraction of tempered martensite is limited to 85% or more. The area fraction of tempered martensite is preferably 90% or more. The area fraction of tempered martensite is more preferably 92% or more and is further preferably 95% or more. On the other hand, the upper limit of the area fraction of tempered martensite is not particularly limited and may be 100%.

55 **[0043]** Here, tempered martensite is measured as follows. A longitudinal cross section of the steel sheet is polished and is subjected to etching in 3 vol% Nital solution. A portion at 1/4 sheet thickness (a location corresponding to 1/4 of the sheet thickness in the depth direction from the steel sheet surface) is observed using SEM in 10 fields of view at a magnification of $\times 2000$. In the microstructure images, tempered martensite is structures that have fine irregularities

inside the structures and contain carbides within the structures. The values thus obtained are averaged to determine tempered martensite.

Retained austenite: less than 5% in terms of volume fraction

[0044] This requirement is a highly important claim component in the present invention. If the volume fraction of retained austenite is 5% or more, it is difficult to achieve 85% or higher YR. The lowering in YR is ascribed to the fact that the amount of retained austenite is so large that strain induced transformation of retained austenite results in low YS. Thus, retained austenite is limited to less than 5% and is preferably 4% or less. The lower limit of retained austenite is not particularly limited. A lower fraction of retained austenite is more preferable, and the fraction may be 0%.

[0045] Here, retained austenite is measured as follows. The steel sheet was polished to expose a face 0.1 mm below 1/4 sheet thickness and was thereafter further chemically polished to expose a face 0.1 mm below the face exposed above. The face was analyzed with an X-ray diffractometer using $\text{CoK}\alpha$ radiation to determine the integral intensity ratios of the diffraction peaks of {200}, {220}, and {311} planes of fcc iron and {200}, {211}, and {220} planes of bcc iron. Nine integral intensity ratios thus obtained were averaged to determine retained austenite.

Total of ferrite and bainitic ferrite: 10% or less in terms of area fraction

[0046] This requirement is a highly important claim component in the present invention. If the total of ferrite and bainitic ferrite is more than 10%, it is difficult to achieve 1320 MPa or higher TS and to achieve 85% or higher YR. The lowering in YR is ascribed to the fact that ferrite and bainitic ferrite are soft microstructures and hasten the occurrence of yielding. Thus, the total of ferrite and bainitic ferrite is limited to 10% or less. The total is preferably 8% or less and is more preferably 5% or less. The lower limit of the total of ferrite and bainitic ferrite is not particularly limited. A smaller fraction is more preferable. The lower limit of the total of ferrite and bainitic ferrite may be 0%.

[0047] Here, the total of ferrite and bainitic ferrite is measured as follows. A longitudinal cross section of the steel sheet is polished and is subjected to etching in 3 vol% Nital solution. A portion at 1/4 sheet thickness (a location corresponding to 1/4 of the sheet thickness in the depth direction from the steel sheet surface) is observed using SEM in 10 fields of view at a magnification of $\times 2000$. In the microstructure images, ferrite and bainitic ferrite are recessed structures with a flat interior. The values thus obtained are averaged to determine the total of ferrite and bainitic ferrite.

[0048] Possible microstructures other than those described above include pearlite, fresh martensite, and acicular ferrite. These microstructures do not affect characteristics as long as their fractions do not exceed 5%, and thus may be present within that range.

$$\text{KAM (S)} / \text{KAM (C)} < 1.00$$

KAM (S): KAM (Kernel average misorientation) value of a superficial portion of the steel sheet, KAM (C): KAM value of a central portion of the steel sheet

[0049] This requirement is a highly important claim component in the present invention. The superficial portion of the steel sheet is located 100 μm below the steel sheet surface toward the center of the sheet thickness. The central portion of the steel sheet is located at 1/2 of the sheet thickness. Studies by the present inventors have revealed that varied distributions of dislocations from the superficial portion to the inside, specifically, KAM (S)/KAM (C) of less than 1.00 is effective for improving the YR and the range of appropriate clearances not leading to delayed fracture. Thus, KAM (S)/KAM (C) is limited to less than 1.00. The lower limit of KAM (S)/KAM (C) is not particularly limited but is preferably 0.80 or more due to production technology limitations.

[0050] Here, the KAM values are measured as follows. First, a test specimen for microstructure observation was sampled from the cold rolled steel sheet. Next, the sampled test specimen was polished by vibration polishing with colloidal silica to expose a cross section in the rolling direction (a longitudinal cross section) for use as observation surface. The observation surface was specular. Next, electron backscatter diffraction (EBSD) measurement was performed. Local crystal orientation data was thus obtained. Here, the SEM magnification was $\times 3000$, the step size was 0.05 μm , the measured region was 20 μm square, and the WD was 15 mm. The local orientation data obtained was analyzed with analysis software: OIM Analysis 7. The analysis was performed with respect to 10 fields of view of the portion at the target sheet thickness, and the results were averaged.

[0051] Prior to the data analysis, cleanup was performed sequentially once using Grain Dilation function of the analysis software (Grain Tolerance Angle: 5, Minimum Grain Size: 2, Single Iteration: ON) and once with Grain CI Standardization function (Grain Tolerance Angle: 5, Minimum Grain Size: 5). Subsequently, measurement points with a CI value > 0.1 were exclusively used for the analysis. The KAM values were displayed as a chart, and the average KAM value of the bcc phase was determined. The analysis here was performed under the following conditions:

Nearest neighbor: 1st,
 Maximum misorientation: 5,
 Perimeter only, and
 Check Set 0-point kernels to maximum misorientation.

$$H_v(Q) - H_v(S) \geq 8$$

Hv (Q): hardness of a portion at 1/4 sheet thickness, Hv (S): hardness of a superficial portion of the steel sheet

[0052] This requirement is a highly important claim component in the present invention. The superficial portion of the steel sheet is located 100 μm below the steel sheet surface toward the center of the sheet thickness. Studies by the present inventors have revealed that variations in hardness from the superficial portion to the inside, specifically, Hv (Q) - Hv (S) of 8 or more is effective for improving the YR and the range of appropriate clearances not leading to delayed fracture. Thus, Hv (Q) - Hv (S) is limited to 8 or more. The upper limit of Hv (Q) - Hv (S) is not particularly limited but is preferably 30 or less due to production technology limitations. Preferred ranges of Hv (Q) and Hv (S) are 400 to 600 and 400 to 600, respectively. Here, the hardness is measured as follows. First, a test specimen for microstructure observation was sampled from the cold rolled steel sheet. Next, the sampled test specimen was polished to expose a cross section in the rolling direction (a longitudinal cross section) for use as observation surface. The observation surface was specular. Next, the hardness was determined using a Vickers tester with a load of 1 kg. The hardness was measured with respect to 10 points at 20 μm intervals at the target sheet thickness. The values of 8 points excluding the maximum hardness and the minimum hardness were averaged.

[0053] Next, a manufacturing method of the present invention will be described.

[0054] In the present invention, a steel material (a steel slab) may be obtained by any known steelmaking method without limitation, such as a converter or an electric arc furnace. To prevent macro-segregation, the steel slab (the slab) is preferably produced by a continuous casting method.

[0055] In the present invention, the slab heating temperature, the slab soaking holding time, and the coiling temperature in hot rolling are not particularly limited. For example, the steel slab may be hot rolled in such a manner that the slab is heated and is then rolled, that the slab is subjected to hot direct rolling after continuous casting without being heated, or that the slab is subjected to a short heat treatment after continuous casting and is then rolled. The slab heating temperature, the slab soaking holding time, the finish rolling temperature, and the coiling temperature in hot rolling are not particularly limited. The slab heating temperature is preferably 1100°C or above. The slab heating temperature is preferably 1300°C or below. The slab soaking holding time is preferably 30 minutes or more. The slab soaking holding time is preferably 250 minutes or less. The finish rolling temperature is preferably Ar₃ transformation temperature or above. Furthermore, the coiling temperature is preferably 350°C or above. The coiling temperature is preferably 650°C or below.

[0056] The hot rolled steel sheet thus produced is pickled. Pickling can remove oxides on the steel sheet surface and is thus important to ensure good chemical convertibility and a high quality of coating in the final high strength steel sheet. Pickling may be performed at a time or several. The hot rolled sheet that has been pickled may be cold rolled directly or may be subjected to heat treatment before cold rolling.

[0057] The rolling reduction in cold rolling and the sheet thickness after rolling are not particularly limited. The rolling reduction in cold rolling is preferably 30% or more. The rolling reduction in cold rolling is preferably 80% or less. The advantageous effects of the present invention may be obtained without limitations on the number of rolling passes and the rolling reduction in each pass.

[0058] The cold rolled steel sheet obtained as described above is annealed. Annealing conditions are as follows.

Annealing temperature T1: 850°C or above and 1000°C or below

[0059] This requirement is a highly important claim component in the present invention. If the annealing temperature T1 is below 850°C, the area fraction of the total of ferrite and bainitic ferrite exceeds 10% to make it difficult to achieve 1320 MPa or higher TS and to achieve 85% or higher YR. Thus, the annealing temperature T1 is limited to 850°C or above. T1 is preferably 860°C or above. T1 is more preferably 870°C or above. However, if the annealing temperature T1 is higher than 1000°C, the prior-austenite grain size excessively increases and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the annealing temperature T1 is limited to 1000°C or below. The annealing temperature T1 is preferably 970°C or below. T1 is more preferably 950°C or below.

Holding time t_1 at the annealing temperature T_1 : 10 seconds or more and 1000 seconds or less

[0060] This requirement is a highly important claim component in the present invention. If the holding time t_1 at the annealing temperature T_1 is less than 10 seconds, austenitization is insufficient with the result that the area fraction of the total of ferrite and bainitic ferrite exceeds 10% to make it difficult to achieve 1320 MPa or higher TS and to achieve 85% or higher YR. Thus, the holding time t_1 at the annealing temperature T_1 is limited to 10 seconds or more. The holding time t_1 at the annealing temperature T_1 is preferably 30 seconds or more. t_1 is more preferably 45 seconds or more. t_1 is still more preferably 60 seconds or more. t_1 is most preferably 100 seconds or more. However, if the holding time at the annealing temperature T_1 is longer than 1000 seconds, the prior-austenite grain size excessively increases and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the holding time t_1 at the annealing temperature T_1 is limited to 1000 seconds or less. The holding time t_1 at the annealing temperature T_1 is preferably 800 seconds or less. t_1 is more preferably 500 seconds or less.

Cooling to 100°C or below after annealing

[0061] In the step of cooling to 100°C or below, austenite is transformed into martensite. To obtain 85% or more martensite, the annealed steel sheet needs to be cooled to 100°C or below. Thus, cooling after annealing is effected to 100°C or below. The lower limit of the cooling complete temperature is not particularly limited but is preferably 0°C or above due to production technology limitations.

Elapsed time t_2 from the time when the temperature reaches 100°C until the start of working: 1000 seconds or less

[0062] This requirement is a highly important claim component in the present invention. If the elapsed time t_2 from the time when the temperature reaches 100°C until the start of working is longer than 1000 seconds, aging of martensite microstructure proceeds and varied amounts of strains are introduced by working into the superficial portion of the steel sheet and the central portion of the steel sheet with the result that KAM (S)/KAM (C) becomes 1.00 or more. As a result, the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the elapsed time t_2 from the time when the temperature reaches 100°C until the start of working is limited to 1000 seconds or less. The elapsed time t_2 from the time when the temperature reaches 100°C until the start of working is preferably 900 seconds or less. t_2 is more preferably 800 seconds or less. The lower limit of the elapsed time t_2 from the time when the temperature reaches 100°C until the start of working is not particularly limited but is preferably 5 seconds or more due to production technology limitations. Studies by the present inventors have shown that the elapsed time from the time when the temperature reaches 100°C until the end of working does not affect the amounts of strains introduced by working into the superficial portion of the steel sheet and the central portion of the steel sheet.

Working start temperature T_2 : 80°C or below

[0063] This requirement is a highly important claim component in the present invention. If the working start temperature T_2 is higher than 80°C, the steel sheet is soft and working introduces varied amounts of strains into the superficial portion of the steel sheet and the central portion of the steel sheet with the result that KAM (S)/KAM (C) becomes 1.00 or more. As a result, the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the working start temperature T_2 is limited to 80°C or below. The working start temperature T_2 is preferably 60°C or below. T_2 is more preferably 50°C or below. The lower limit of the working start temperature T_2 is not particularly limited but is preferably 0°C or above due to production technology limitations.

Equivalent plastic strain: 0.10% or more and 5.00% or less

[0064] This requirement is a highly important claim component in the present invention. If the equivalent plastic strain is less than 0.10%, the amount of working is small and KAM (S)/KAM (C) becomes 1.00 or more. As a result, the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the equivalent plastic strain is limited to 0.10% or more. The plastic equivalent strain is preferably 0.15% or more. The plastic equivalent strain is more preferably 0.20% or more. If the equivalent plastic strain is more than 5.00%, the influences by working are equal between the superficial portion of the steel sheet and the central portion of the steel sheet with the result that KAM (S)/KAM (C) becomes 1.00 or more. As a result, the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. The upper limit of the equivalent plastic strain is 5.00% or less due to production technology limitations. Thus, the equivalent plastic strain is limited to 5.00% or less. The equivalent plastic strain is preferably 4.00% or less. The equivalent plastic strain is more preferably 2.00% or less. The equivalent plastic strain is still more preferably 1.00% or less.

[0065] The working step before tempering is preferably performed under conditions where strain is applied by two or more separate working operations, and the total of the equivalent plastic strains applied in the working operations is 0.10% or more.

[0066] When the equivalent plastic strain in the first working operation is less than 0.10%, the total of the equivalent plastic strains may be brought to 0.10% or more by the second and subsequent working operations. Even in this case, KAM (S)/KAM (C) becomes less than 1.00, and the YR and the range of appropriate clearances not leading to delayed fracture are enhanced. Thus, the working step before tempering may apply strain by two or more separate working operations as long as the total of the equivalent plastic strains applied in the working operations is 0.10% or more. Incidentally, there is no limitation on the elapsed time from when the temperature reaches 100°C until the start of the second and subsequent working operations, because the mobility of dislocations in martensite has been lowered by the first working operation.

[0067] Here, the working process may be typically temper rolling or tension leveling. The equivalent plastic strain in temper rolling is the ratio by which the steel sheet is elongated and may be determined from the change in the length of the steel sheet before and after the working. The equivalent plastic strain of the steel sheet in leveler processing was calculated by the method of Reference 1 below. The data inputs described below were used in the calculation. Regarding the work hardening behavior, the material was assumed to be a linear hardening elastoplastic material. Bausinger hardening and the decrease in tension due to bend loss were ignored. Misaka's formula was used as the formula of bending curvature.

- Sheet thickness breakdown: 31 divisions
- Young's modulus: 21000 kgf/mm²
- Poisson's ratio: 0.3
- Yield stress: 111 kgf/mm²
- Plastic coefficient: 1757 kgf/mm²

[Reference 1] Yoshisuke Misaka, Takeshi Masui; Sosei to Kakou (Journal of JSTP), 17 (1976), 988.

Incidentally, the working may be any common strain imparting technique other than those described above. For example, the working may be performed with a continuous stretcher leveler or a roller leveler.

Tempering temperature T3: 100°C or above and 400°C or below

[0068] This requirement is a highly important claim component in the present invention. If the tempering temperature T3 is lower than 100°C, the carbon diffusion distance is so short that the hardness of the steel sheet surface and the inside of the steel sheet is lowered and Hv (Q) - Hv (S) becomes less than 8. As a result, the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the tempering temperature T3 is limited to 100°C or above. The tempering temperature T3 is preferably 150°C or above. T3 is more preferably 170°C or above. T3 is still more preferably 200°C or above. However, if the tempering temperature T3 is higher than 400°C, tempering of martensite proceeds to make it difficult to achieve 1320 MPa or higher TS. Thus, the tempering temperature T3 is limited to 400°C or below. The tempering temperature T3 is preferably 350°C or below. T3 is more preferably 300°C or below. T3 is still more preferably 280°C or below.

Holding time t3 at the tempering temperature T3: 1.0 second or more and 1000.0 seconds or less

[0069] This requirement is a highly important claim component in the present invention. If the holding time t3 at the tempering temperature T3 is less than 1.0 second, the carbon diffusion distance is so short that the hardness of the steel sheet surface and the inside of the steel sheet is lowered and Hv (Q) - Hv (S) becomes less than 8 with the result that the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the holding time t3 at the tempering temperature T3 is limited to 1.0 second or more. The holding time t3 at the tempering temperature T3 is preferably 5.0 seconds or more. t3 is more preferably 50.0 seconds or more. t3 is still more preferably 100.0 seconds or more. However, if the holding time t3 at the tempering temperature T3 is longer than 1000.0 seconds, tempering of martensite proceeds to make it difficult to achieve 1320 MPa or higher TS. Thus, the holding time t3 at the tempering temperature T3 is limited to 1000.0 seconds or less. The holding time t3 at the tempering temperature T3 is preferably 800.0 seconds or less. t3 is more preferably 600.0 seconds or less. t3 is still more preferably 500.0 seconds or less.

Cooling rate θ_1 from the tempering temperature T3 to 80°C: 100°C/sec or less

[0070] This requirement is a highly important claim component in the present invention. If the cooling rate θ_1 from the

tempering temperature T3 to 80°C is higher than 100°C/sec, the carbon diffusion distance is so short that the hardness of the steel sheet surface and the inside of the steel sheet is lowered and Hv (Q) - Hv (S) becomes less than 8 with the result that the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the cooling rate θ_1 from the tempering temperature T3 to 80°C is limited to 100°C/sec or less. The cooling rate θ_1 from the tempering temperature T3 to 80°C is preferably 50°C/sec or less. The lower limit of the cooling rate θ_1 from the tempering temperature T3 to 80°C is not particularly limited but is preferably 10°C/sec or more due to production technology limitations.

[0071] Below 80°C, cooling is not particularly limited and the steel sheet may be cooled to a desired temperature in an appropriate manner. Incidentally, the desired temperature is preferably about room temperature.

[0072] Furthermore, the high strength steel sheet described above may be worked again under conditions where the amount of equivalent plastic strain is 0.10% or more and 5.00% or less. Here, the target amount of equivalent plastic strain may be applied at a time or several.

[0073] When the high strength steel sheet is a product that is traded, the steel sheet is usually traded after being cooled to room temperature.

[0074] The high strength steel sheet may be subjected to coating treatment during annealing or after annealing. The phrase "during annealing" means a period from the end of the holding time t1 at the annealing temperature T1 until when the steel sheet that has been held for t3 at the tempering temperature T3 is cooled to room temperature. The phrase "after annealing" means a period after the steel sheet is cooled to room temperature.

For example, the coating treatment during annealing may be hot-dip galvanizing treatment and alloying treatment following the hot-dip galvanizing treatment which are performed when the steel sheet that has been held at the annealing temperature T1 is being cooled to 100°C or below. For example, the coating treatment after annealing may be Zn-Ni electrical alloying coating treatment or pure Zn electroplated coating treatment performed after the steel sheet that has been held for t3 at the tempering temperature T3 is cooled to room temperature. A coated layer may be formed by electroplated coating, or hot-dip zinc-aluminum-magnesium alloy coating may be applied. In the above coating treatment, examples were described focusing on zinc coating, the types of coating metals, such as Zn coating and Al coating, are not particularly limited. Other conditions in the manufacturing method are not particularly limited. From the point of view of productivity, the series of treatments including annealing, hot-dip galvanizing, and alloying treatment of the coated zinc layer is preferably performed on hot-dip galvanizing line, that is CGL (continuous galvanizing line). To control the coating weight of the coated layer, the hot-dip galvanizing treatment may be followed by wiping. Conditions for operations, such as coating, other than those conditions described above may be determined in accordance with the usual hot-dip galvanizing technique.

[0075] After the coating treatment during annealing or after annealing, the steel sheet may be worked again under conditions where the amount of equivalent plastic strain is 0.10% or more and 5.00 or less. Here, the target amount of equivalent plastic strain may be applied at a time or several.

EXAMPLES

[0076] Steels having a chemical composition described in Table 1-1 or Table 1-2, with the balance being Fe and incidental impurities, were smelted in a converter and were continuously cast into slabs. Next, the slabs obtained were heated, hot rolled, pickled, cold rolled, and subjected to annealing treatment, working, and tempering treatment described in Table 2-1, Table 2-2, and Table 2-3. High strength cold rolled steel sheets having a sheet thickness of 0.6 to 2.2 mm were thus obtained. Incidentally, some of the steel sheets were subjected to coating treatment after annealing.

[0077] In EXAMPLES Nos. 77, 82, 85, 88, and 91, the slabs fractured in the casting step and thus the test was discontinued.

[0078] The high strength cold rolled steel sheets obtained as described above were used as test steels. Tensile characteristics and delayed fracture resistance were evaluated in accordance with the following test methods.

(Microstructure observation)

[0079] The area fraction of tempered martensite, the volume fraction of retained austenite, and the total of the area fraction of ferrite and the area fraction of bainitic ferrite were determined in accordance with the methods described hereinabove.

(KAM values)

[0080] The KAM value of a superficial portion of the steel sheet and the KAM value of a central portion of the steel sheet were determined in accordance with the method described hereinabove.

(Hardness test)

[0081] The hardness of a portion at 1/4 sheet thickness and the hardness of a superficial portion of the steel sheet were determined in accordance with the method described hereinabove.

(Tensile test)

[0082] A JIS No. 5 test specimen (gauge length: 50 mm, width of parallel portion: 25 mm) was sampled so that the longitudinal direction of the test specimen would be perpendicular to the rolling direction. A tensile test was performed in accordance with JIS Z 2241 under conditions where the crosshead speed was 1.67×10^{-1} mm/sec. YS and TS were thus measured. In the present invention, 1320 MPa or higher TS was judged to be acceptable, and 85% or higher yield ratio (YR) was judged to be acceptable. The YR is determined from the following formula (3):

$$YR = 100 \times YS/TS \cdots (3)$$

(Range of appropriate clearances not leading to delayed fracture)

[0083] The range of appropriate clearances not leading to delayed fracture was determined by the following method. Test specimens having a size of 16 mm \times 75 mm were prepared by shearing in such a manner that the longitudinal direction would be perpendicular to the rolling direction. The rake angle in the shearing process was constant at 0°, and the shear clearance was changed from 5 to 10, 15, 20, 25, 30, and 35%. The test specimens were four-point loaded in accordance with ASTM (G39-99) so that 1000 MPa stress was applied to the bend apex. The loaded test specimens were immersed in pH 3 hydrochloric acid at 25°C for 100 hours. The rating was "×" when the shear clearances that did not cause cracking ranged below 10%. The rating was "o" when the shear clearances ranged to 10% or above but below 15%. The rating was "⊙" when the shear clearances that did not cause cracking ranged to 15% or above. The range of appropriate clearances not leading to delayed fracture was evaluated as excellent when the shear clearances that did not cause cracking ranged to 10% or above.

[0084] As described in Table 3-1, Table 3-2, and Table 3-3, INVENTIVE EXAMPLES achieved 1320 MPa or higher TS, 85% or higher YR, and an excellent range of appropriate clearances not leading to delayed fracture. In contrast, COMPARATIVE EXAMPLES were unsatisfactory in one or more of TS, YR, and the range of appropriate clearances not leading to delayed fracture.

[Table 1-1]

Steels	Chemical composition (mass%)													Remarks
	C	Si	Mn	P	S	Al	N	H	Ti	B	Nb	Cu	Others	
A	0.21	0.71	2.96	0.010	0.0015	0.037	0.0018	0.0000	0.015					Compliant steel
B	0.20	0.90	3.02	0.011	0.0007	0.032	0.0068	0.0000						Compliant steel
C	0.20	0.85	2.89	0.005	0.0009	0.054	0.0023	0.0000		0.0015				Compliant steel
D	0.18	0.28	1.01	0.015	0.0008	0.047	0.0033	0.0000			0.005			Compliant steel
E	0.19	0.14	1.11	0.005	0.0013	0.012	0.0025	0.0000						Compliant steel
F	0.19	0.11	1.01	0.006	0.0011	0.057	0.0010	0.0000				0.11		Compliant steel
G	0.16	0.91	2.95	0.006	0.0015	0.023	0.0010	0.0000	0.041					Compliant steel
H	0.14	0.78	3.05	0.012	0.0006	0.045	0.0028	0.0000						Comparative steel
I	0.44	0.67	2.77	0.005	0.0006	0.034	0.0039	0.0000			0.016			Compliant steel
J	0.46	0.69	3.12	0.012	0.0005	0.012	0.0041	0.0000						Comparative steel
K	0.18	0.11	2.73	0.008	0.0012	0.025	0.0063	0.0000						Compliant steel
L	0.21	1.91	2.96	0.011	0.0008	0.011	0.0070	0.0000						Compliant steel
M	0.18	2.11	3.03	0.006	0.0008	0.036	0.0033	0.0000						Comparative steel
N	0.20	0.78	1.12	0.011	0.0006	0.015	0.0060	0.0000						Compliant steel
O	0.19	0.75	0.41	0.011	0.0007	0.026	0.0050	0.0000						Comparative steel
P	0.21	0.94	3.45	0.013	0.0006	0.044	0.0056	0.0000						Compliant steel
Q	0.20	0.77	3.55	0.009	0.0007	0.021	0.0070	0.0000						Comparative steel
R	0.20	0.70	3.02	0.099	0.0013	0.018	0.0066	0.0000						Compliant steel
S	0.19	0.61	2.78	0.121	0.0006	0.045	0.0031	0.0000						Comparative steel
T	0.21	0.67	3.04	0.006	0.0182	0.021	0.0030	0.0000						Compliant steel
U	0.22	0.94	2.96	0.012	0.0222	0.028	0.0048	0.0000						Comparative steel
V	0.19	0.99	2.84	0.010	0.0011	0.976	0.0029	0.0000						Compliant steel
W	0.18	0.67	2.76	0.015	0.0010	1.135	0.0015	0.0000						Comparative steel
X	0.22	0.85	3.16	0.006	0.0011	0.014	0.0089	0.0000						Compliant steel

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(continued)

Steels	Chemical composition (mass%)													Remarks
	C	Si	Mn	P	S	Al	N	H	Ti	B	Nb	Cu	Others	
<u>Y</u>	0.20	0.87	2.85	0.005	0.0009	0.027	0.0112	0.0000						Comparative steel
Z	0.21	0.84	2.98	0.014	0.0014	0.040	0.0046	0.0012						Compliant steel
Underlines indicate being outside of the range of the present invention. Blanks indicate that the element was not added intentionally.														

[Table 1-2]

Steels	Chemical composition (mass%)												Remarks
	C	Si	Mn	P	S	Al	N	H	Ti	B	Nb	Cu	
AA	0.19	0.76	2.77	0.006	0.0007	0.056	0.0030	0.0035					Comparative steel
AB	0.21	0.91	2.96	0.005	0.0005	0.011	0.0033	0.0000		0.0028	0.019	0.15	Compliant steel
AC	0.21	0.64	3.01	0.006	0.0005	0.055	0.0038	0.0000	0.085	0.0022	0.029	0.18	Compliant steel
AD	0.20	0.81	2.82	0.010	0.0014	0.032	0.0062	0.0000	0.125	0.0017	0.028	0.12	Comparative steel
AE	0.19	0.89	3.15	0.010	0.0007	0.038	0.0032	0.0000	0.026		0.029	0.12	Compliant steel
AF	0.20	0.72	3.07	0.011	0.0013	0.010	0.0056	0.0000	0.021	0.0076	0.024	0.17	Compliant steel
AG	0.20	0.64	3.19	0.011	0.0012	0.016	0.0028	0.0000	0.045	0.0124	0.029	0.17	Comparative steel
AH	0.19	0.60	2.86	0.009	0.0007	0.015	0.0069	0.0000	0.019	0.0025		0.19	Compliant steel
AI	0.19	0.62	2.85	0.009	0.0011	0.034	0.0048	0.0000	0.030	0.0028	0.086	0.11	Compliant steel
AJ	0.19	0.89	3.16	0.009	0.0012	0.016	0.0047	0.0000	0.037	0.0014	0.135	0.12	Comparative steel
AK	0.22	0.68	3.11	0.007	0.0014	0.014	0.0018	0.0000	0.026	0.0018	0.025		Compliant steel
AL	0.18	0.62	2.83	0.007	0.0012	0.016	0.0022	0.0000	0.024	0.0026	0.026	0.96	Compliant steel
AM	0.21	0.79	2.99	0.015	0.0011	0.020	0.0042	0.0000	0.021	0.0026	0.012	1.02	Comparative steel
AN	0.19	0.22	1.33	0.010	0.0011	0.053	0.0047	0.0000					Compliant steel
AO	0.21	0.83	2.86	0.013	0.0011	0.040	0.0011	0.0000					Compliant steel
AP	0.21	0.18	1.00	0.014	0.0012	0.016	0.0035	0.0000					Compliant steel
AQ	0.21	0.95	3.08	0.009	0.0008	0.011	0.0022	0.0000					Compliant steel
AR	0.22	0.25	1.17	0.013	0.0013	0.056	0.0067	0.0000					Compliant steel
AS	0.20	0.99	3.19	0.009	0.0006	0.047	0.0011	0.0000					Compliant steel
AT	0.22	0.15	1.16	0.015	0.0006	0.031	0.0033	0.0000					Compliant steel
AU	0.21	0.71	2.82	0.013	0.0009	0.022	0.0034	0.0000					Compliant steel
AV	0.20	0.15	1.17	0.005	0.0008	0.017	0.0032	0.0000					Compliant steel
AW	0.21	0.61	2.79	0.008	0.0012	0.016	0.0062	0.0000					Compliant steel
AX	0.22	0.26	1.04	0.013	0.0006	0.059	0.0055	0.0000	0.044	0.0030	0.006	0.12	Compliant steel

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(continued)

Steels	Chemical composition (mass%)													Remarks
	C	Si	Mn	P	S	Al	N	H	Ti	B	Nb	Cu	Others	
AY	0.17	0.15	1.03	0.013	0.0008	0.039	0.0049	0.0000						Compliant steel
AZ	0.33	0.28	1.30	0.008	0.0014	0.049	0.0063	0.0000						Compliant steel
Underlines indicate being outside of the range of the present invention. Blanks indicate that the element was not added intentionally.														

[Table 2-1]

No.	Steels	Sheet thickness (mm)	Annealing temp. T1 (°C)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100°C until start of working (sec)	Working start temp. T2 (°C)	Equivalent plastic strain (%)	Working operations (times)	Tempering temp. T3 (°C)	Holding time t3 (sec)	Cooling rate from tempering temp. T3 to 80°C (°C/sec)	Type of product (*)	Remarks
1	A	1.4	875	105	729	44	0.44	1	237	160.5	29	CR	INV. EX.
2	B	1.4	870	151	653	25	0.55	1	250	62.0	34	CR	INV. EX.
3	B	1.4	855	119	710	47	0.42	1	177	121.1	50	CR	INV. EX.
4	B	1.4	842	168	763	27	0.53	1	239	236.5	26	CR	COMP. EX.
5	B	1.4	968	155	731	41	0.50	1	176	248.2	36	CR	INV. EX.
6	B	1.4	989	133	653	42	0.40	1	260	176.5	28	CR	INV. EX.
7	B	1.4	874	11	795	39	0.47	1	207	219.3	34	CR	INV. EX.
8	B	1.4	879	3	722	35	0.33	1	293	161.0	40	CR	COMP. EX.
9	B	1.4	878	956	777	47	0.35	1	266	236.0	49	CR	INV. EX.
10	B	1.4	868	992	711	47	0.32	1	198	263.7	34	CR	INV. EX.
11	B	1.4	875	106	22	30	0.54	1	292	185.9	45	CR	INV. EX.
12	B	1.4	879	71	723	27	0.37	2	215	294.1	50	CR	INV. EX.
13	B	1.4	874	179	986	48	0.39	1	211	276.5	34	CR	INV. EX.
14	B	1.4	860	146	1065	25	0.35	1	293	205.7	32	CR	COMP. EX.
15	B	1.4	862	72	758	12	0.54	1	218	138.9	28	CR	INV. EX.
16	B	1.4	862	158	792	37	0.52	3	224	283.1	26	CR	INV. EX.
17	B	1.4	861	56	730	77	0.44	1	150	217.0	41	CR	INV. EX.
18	B	1.4	877	98	614	95	0.42	1	279	245.1	26	CR	COMP. EX.
19	B	1.4	880	107	683	32	0.13	1	180	243.4	32	CR	INV. EX.
20	B	1.4	879	160	670	48	0.08	1	246	258.0	48	CR	COMP. EX.

(continued)

No.	Steels	Sheet thickness (mm)	Annealing temp. T1 (°C)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100°C until start of working (sec)	Working start temp. T2 (°C)	Equivalent plastic strain (%)	Working operations (times)	Tempering temp. T3 (°C)	Holding time t3 (sec)	Cooling rate θ_1 from tempering temp. T3 to 80°C (°C/sec)	Type of product (*)	Remarks
21	B	1.4	866	112	695	28	4.20	1	269	170.2	31	CR	INV. EX.
22	B	1.4	871	170	629	29	0.40	4	197	224.4	32	CR	INV. EX.
23	B	1.4	879	83	652	35	0.54	1	106	200.6	30	CR	INV. EX.
24	B	1.4	865	151	612	33	0.39	1	90	228.7	31	CR	COMP. EX.
25	B	1.4	871	132	613	46	0.38	1	391	257.8	39	CR	INV. EX.
26	B	1.4	877	147	743	48	0.33	1	392	170.8	29	CR	INV. EX.
27	B	1.4	869	58	668	49	0.57	1	275	4.7	29	CR	INV. EX.
28	B	1.4	872	154	700	36	0.40	1	173	2.2	45	CR	INV. EX.
29	B	1.4	866	101	709	27	0.58	1	292	1.2	27	CR	INV. EX.
30	B	1.4	878	109	656	28	0.55	1	217	0.8	30	CR	COMP. EX.
31	B	1.4	879	180	690	48	0.34	1	232	988.0	38	CR	INV. EX.
32	B	1.4	872	175	725	28	0.54	1	200	998.5	49	CR	INV. EX.
33	B	1.4	879	151	610	45	0.58	1	218	146.7	5	CR	INV. EX.
34	B	1.4	870	85	792	39	0.58	4	191	280.5	26	CR	INV. EX.
35	B	1.4	877	161	682	46	0.49	1	228	256.5	98	CR	INV. EX.
Underlines indicate being outside of the range of the present invention. (*)CR: Cold rolled steel sheet (without coating)													

[Table 2-2]

No.	Steels	Sheet thickness (mm)	Annealing temp. T1 (°C)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100°C until start of working (sec)	Working start temp. T2 (°C)	Equivalent plastic strain (%)	Working operations (times)	Tempering temp. T3 (°C)	Holding time t3 (sec)	Cooling rate θ_1 from tempering temp. T3 to 80°C (°C/sec)	Type of product (*)	Remarks
36	B	1.4	872	58	706	29	0.52	1	204	228.1	125	CR	COMP. EX.
37	C	0.8	880	65	621	46	0.42	1	187	198.8	41	CR	INV. EX.
38	D	2.0	864	133	772	30	0.48	1	255	245.6	29	CR	INV. EX.
39	E	1.4	869	106	644	47	0.31	1	179	153.0	45	CR	INV. EX.
40	E	1.4	855	67	651	29	0.60	1	294	267.6	46	CR	INV. EX.
41	E	1.4	879	151	784	30	0.51	1	173	252.7	37	CR	INV. EX.
42	E	1.4	880	12	654	31	0.47	1	286	117.4	46	CR	INV. EX.
43	E	1.4	876	946	759	27	0.57	1	288	270.3	25	CR	INV. EX.
44	E	1.4	865	182	20	28	0.44	1	269	195.9	30	CR	INV. EX.
45	E	1.4	865	185	996	28	0.37	1	277	164.1	38	CR	INV. EX.
46	E	1.4	877	54	720	11	0.53	1	171	140.1	37	CR	INV. EX.
47	E	1.4	864	86	663	79	0.33	1	287	161.4	43	CR	INV. EX.
48	E	1.4	860	190	635	43	0.13	1	228	114.9	28	CR	INV. EX.
49	E	1.4	867	70	651	47	4.22	1	172	169.5	33	CR	INV. EX.
50	E	1.4	877	117	755	49	0.51	1	105	245.2	28	CR	INV. EX.
51	E	1.4	866	58	650	50	0.38	1	381	158.2	38	CR	INV. EX.
52	E	1.4	870	84	641	50	0.40	1	228	4.6	50	CR	INV. EX.
53	E	1.4	872	191	693	46	0.55	1	245	2.1	31	CR	INV. EX.
54	E	1.4	869	158	769	46	0.42	1	170	1.1	30	CR	INV. EX.
55	E	1.4	880	117	787	37	0.46	1	225	991.0	28	CR	INV. EX.

(continued)

No.	Steels	Sheet thickness (mm)	Annealing temp. T1 (°C)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100°C until start of working (sec)	Working start temp. T2 (°C)	Equivalent plastic strain (%)	Working operations (times)	Tempering temp. T3 (°C)	Holding time t3 (sec)	Cooling rate θ_1 from tempering temp. T3 to 80°C (°C/sec)	Type of product (*)	Remarks
56	E	1.4	862	85	712	33	0.35	1	186	163.9	4	CR	INV. EX.
57	E	1.4	877	157	748	30	0.49	1	296	240.2	88	CR	INV. EX.
58	F	1.2	861	132	602	44	0.42	1	274	198.2	40	CR	INV. EX.
59	G	1.2	874	149	697	32	0.43	1	253	135.5	29	GA	INV. EX.
60	H	1.2	874	116	722	49	0.36	1	222	231.8	44	GA	COMP. EX.
61	I	1.2	861	138	641	49	0.50	1	294	104.5	32	GA	INV. EX.
62	J	1.2	874	135	701	41	0.47	1	263	168.6	35	GA	COMP. EX.
63	K	1.2	865	125	757	28	0.56	1	221	147.9	41	GA	INV. EX.
64	L	1.2	867	103	774	38	0.31	1	253	185.8	45	CR	INV. EX.
65	M	1.2	864	126	651	36	0.56	1	152	121.6	37	CR	COMP. EX.
66	N	1.2	871	95	702	35	0.38	1	244	100.0	37	GA	INV. EX.
67	O	1.6	876	174	613	26	0.37	1	267	179.2	28	GA	COMP. EX.
68	P	1.6	861	52	621	35	0.51	1	196	202.4	47	GI	INV. EX.
69	Q	1.6	873	158	672	48	0.50	1	278	181.0	27	GA	COMP. EX.
70	R	1.6	864	135	617	33	0.58	1	262	293.6	45	GA	INV. EX.

Underlines indicate being outside of the range of the present invention.

(*) CR: Cold rolled steel sheet (without coating), GI: Hot-dip galvanized steel sheet (without alloying treatment), GA: Galvannealed steel sheet

[Table 2-3]

No.	Steels	Sheet thickness (mm)	Annealing temp. T1 (°C)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100°C until start of working (sec)	Working start temp. T2 (°C)	Equivalent plastic strain (%)	Working operations (times)	Tempering temp. T3 (°C)	Holding time t3 (sec)	Cooling rate θ 1 from tempering temp. T3 to 80°C (°C/sec)	Type of product (*)	Remarks
71	<u>S</u>	1.6	875	160	601	39	0.52	1	191	159.0	48	GA	COMP. EX.
72	<u>T</u>	1.6	878	72	623	41	0.33	1	233	169.5	37	GA	INV. EX.
73	<u>U</u>	1.6	878	182	742	28	0.55	1	222	156.0	29	GI	COMP. EX.
74	<u>V</u>	1.6	877	179	749	47	0.42	2	296	280.5	31	GA	INV. EX.
75	<u>W</u>	1.4	879	170	613	37	0.56	1	256	195.7	39	GA	COMP. EX.
76	<u>X</u>	1.4	870	51	759	36	0.37	1	159	156.5	28	GA	INV. EX.
77	<u>Y</u>	The slab fractured during casting and the test was discontinued.											
78	<u>Z</u>	1.4	869	76	727	34	0.38	1	164	201.6	47	GA	INV. EX.
79	<u>AA</u>	1.4	864	63	756	43	0.32	1	161	169.5	44	GI	COMP. EX.
80	<u>AB</u>	1.4	876	52	644	47	0.38	1	166	280.4	44	GA	INV. EX.
81	<u>AC</u>	1.4	864	78	765	49	0.56	1	182	175.5	32	GA	INV. EX.
82	<u>AD</u>	The slab fractured during casting and the test was discontinued.											
83	<u>AE</u>	1.4	871	123	757	37	0.58	1	276	233.2	29	GA	INV. EX.
84	<u>AF</u>	1.4	878	50	669	46	0.31	1	250	253.8	45	CR	INV. EX.
85	<u>AG</u>	The slab fractured during casting and the test was discontinued.											
86	<u>AH</u>	1.4	870	161	682	47	0.52	3	218	228.3	48	GA	INV. EX.
87	<u>AI</u>	1.4	860	181	628	48	0.52	1	273	125.0	28	GA	INV. EX.
88	<u>AJ</u>	The slab fractured during casting and the test was discontinued.											
89	<u>AK</u>	1.4	864	74	654	28	0.50	1	293	226.1	38	GA	INV. EX.
90	<u>AL</u>	1.4	860	173	730	50	0.46	1	223	289.8	41	GA	INV. EX.

(continued)

No.	Steels	Sheet thickness (mm)	Annealing temp. T1 (°C)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100°C until start of working (sec)	Working start temp. T2 (°C)	Equivalent plastic strain (%)	Working operations (times)	Tempering temp. T3 (°C)	Holding time t3 (sec)	Cooling rate 0.1 from tempering temp. T3 to 80°C (°C/sec)	Type of product (*)	Remarks
91	AM												COMP. EX.
92	AN	1.4	864	193	641	33	0.39	1	199	246.6	43	GA	INV. EX.
93	AO	1.4	877	99	669	42	0.51	1	211	195.4	44	CR	INV. EX.
94	AP	1.4	879	161	731	42	0.48	1	285	260.8	44	CR	INV. EX.
95	AQ	1.4	863	105	681	35	0.44	1	167	194.5	28	CR	INV. EX.
96	AR	1.4	872	145	794	46	0.41	4	172	189.4	32	CR	INV. EX.
97	AS	1.4	869	156	788	32	0.57	1	251	293.6	49	CR	INV. EX.
98	AT	1.4	877	200	767	47	0.55	1	160	299.8	34	CR	INV. EX.
99	AU	1.4	870	107	681	43	0.55	4	225	293.9	45	CR	INV. EX.
100	AV	1.4	864	136	670	41	0.52	1	285	104.4	28	CR	INV. EX.
101	AW	1.4	876	60	664	29	0.41	1	262	221.4	33	CR	INV. EX.
102	AX	1.4	864	85	750	32	0.33	1	243	295.8	43	CR	INV. EX.
103	AY	0.8	879	195	693	31	0.39	1	211	272.2	45	EG	INV. EX.
104	AZ	2.0	879	136	669	33	0.36	1	180	109.4	42	EG	INV. EX.
Underlines indicate being outside of the range of the present invention.													
(*) CR: Cold rolled steel sheet (without coating), GI: Hot-dip galvanized steel sheet (without alloying treatment), GA: Galvannealed steel sheet, EG: Electroalvanized steel sheet													

[Table 3-1]

No.	Steels	Sheet thick- ness (mm)	Tempered martensite (%)	Retained austenite (%)	Total of ferrite and bainitic ferrite (%)	KAM(S) (°)	KAM(C) (°)	KAM(S) /KAM (C)	Hv(Q)	Hv(S)	Hv(Q)-Hv (S)	YS (MPa)	TS (MPa)	YR (%)	Range of ap- propriate clearances not leading to de- layed fracture	Remarks
1	A	1.4	98	2	0	0.504	0.536	0.941	516	498	18	1451	1560	93	⊙	INV. EX.
2	B	1.4	99	1	0	0.501	0.538	0.931	508	491	17	1418	1538	92	⊙	INV. EX.
3	B	1.4	91	1	8	0.508	0.535	0.949	473	460	13	1235	1440	86	⊙	INV. EX.
4	B	1.4	83	3	14	0.499	0.531	0.940	414	395	19	1024	1240	83	⊙	COMP. EX.
5	B	1.4	99	1	0	0.514	0.541	0.950	548	534	14	1503	1674	90	○	INV. EX.
6	B	1.4	99	1	0	0.502	0.534	0.940	511	491	20	1455	1538	95	○	INV. EX.
7	B	1.4	90	1	9	0.505	0.537	0.939	458	441	17	1206	1384	87	⊙	INV. EX.
8	B	1.4	83	2	15	0.516	0.537	0.960	391	371	20	957	1159	83	⊙	COMP. EX.
9	B	1.4	99	1	0	0.510	0.537	0.950	503	483	20	1431	1513	95	○	INV. EX.
10	B	1.4	100	0	0	0.509	0.536	0.950	528	512	16	1467	1605	91	○	INV. EX.
11	B	1.4	99	1	0	0.487	0.540	0.901	498	472	26	1469	1478	99	⊙	INV. EX.
12	B	1.4	99	1	0	0.517	0.538	0.960	530	514	16	1471	1609	91	⊙	INV. EX.
13	B	1.4	99	1	0	0.528	0.537	0.984	516	506	10	1408	1585	89	⊙	INV. EX.
14	B	1.4	98	2	0	0.540	0.535	1.009	480	476	4	1218	1489	82	×	COMP. EX.
15	B	1.4	99	1	0	0.484	0.537	0.901	530	503	27	1561	1577	99	⊙	INV. EX.
16	B	1.4	100	0	0	0.505	0.537	0.941	522	503	19	1479	1577	94	⊙	INV. EX.
17	B	1.4	100	0	0	0.533	0.538	0.990	544	535	9	1437	1675	86	○	INV. EX.
18	B	1.4	100	0	0	0.541	0.538	1.004	481	481	0	1186	1509	79	×	COMP. EX.
19	B	1.4	99	1	0	0.532	0.541	0.984	538	529	9	1459	1659	88	○	INV. EX.
20	B	1.4	100	0	0	0.557	0.537	1.039	495	488	7	1290	1532	84	×	COMP. EX.
21	B	1.4	99	1	0	0.485	0.539	0.900	513	500	13	1350	1531	88	⊙	INV. EX.
22	B	1.4	100	0	0	0.509	0.536	0.950	538	523	15	1486	1640	91	⊙	INV. EX.

(continued)

No.	Steels	Sheet thickness (mm)	Tempered martensite (%)	Retained austenite (%)	Total of ferrite and bainitic ferrite (%)	KAM(S) (°)	KAM(C) (°)	KAM(S)/KAM (C)	Hv(Q)	Hv(S)	Hv(Q)-Hv (S)	YS (MPa)	TS (MPa)	YR (%)	Range of appropriate clearances not leading to delayed fracture	Remarks
23	B	1.4	99	1	0	0.499	0.537	0.930	475	466	9	1249	1459	86	○	INV. EX.
24	B	1.4	99	1	0	0.504	0.536	0.941	526	525	<u>1</u>	1309	1648	79	×	COMP. EX.
25	B	1.4	99	1	0	0.510	0.537	0.950	473	460	13	1180	1334	88	⊙	INV. EX.
26	B	1.4	100	0	0	0.510	0.537	0.950	414	395	19	1134	1331	85	⊙	INV. EX.
27	B	1.4	100	0	0	0.502	0.533	0.940	530	521	9	1425	1633	87	○	INV. EX.
28	B	1.4	99	1	0	0.512	0.533	0.960	523	514	9	1422	1610	88	○	INV. EX.
29	B	1.4	98	2	0	0.491	0.533	0.920	520	511	9	1394	1601	87	○	INV. EX.
30	B	1.4	99	1	0	0.502	0.541	0.929	519	520	<u>-1</u>	1271	1634	78	×	COMP. EX.
31	B	1.4	99	1	0	0.514	0.535	0.960	474	449	25	1388	1408	99	⊙	INV. EX.
32	B	1.4	99	1	0	0.506	0.539	0.940	423	397	26	1238	1334	93	⊙	INV. EX.
33	B	1.4	99	1	0	0.503	0.535	0.941	535	511	24	1566	1601	98	⊙	INV. EX.
34	B	1.4	98	2	0	0.507	0.540	0.940	539	522	17	1506	1633	92	⊙	INV. EX.
35	B	1.4	98	2	0	0.506	0.539	0.940	519	509	10	1407	1596	88	○	INV. EX.
Underlines indicate being outside of the range of the present invention.																

[Table 3-2]

No.	Steels	Sheet thick- ness (mm)	Tempered martensite (%)	Retained austenite (%)	Total of ferrite and bainitic ferrite (%)	KAM(S) (°)	KAM(C) (°)	KAM(S) /KAM (C)	Hv(Q)	Hv(S)	Hv(Q)-Hv (S)	YS (MPa)	TS (MPa)	YR (%)	Range of ap- propriate clearances not leading to de- layed fracture	Remarks
36	B	1.4	100	0	0	0.507	0.540	0.940	523	521	2	1309	1632	80	×	COMP. EX.
37	C	0.8	98	2	0	0.503	0.535	0.941	529	514	15	1457	1608	91	○	INV. EX.
38	D	2.0	99	1	0	0.504	0.536	0.941	509	488	21	1460	1530	95	○	INV. EX.
39	E	1.4	98	2	0	0.517	0.538	0.960	546	534	12	1473	1670	88	○	INV. EX.
40	E	1.4	92	1	7	0.498	0.536	0.930	447	425	22	1137	1333	85	○	INV. EX.
41	E	1.4	98	2	0	0.506	0.539	0.940	548	533	15	1516	1673	91	○	INV. EX.
42	E	1.4	91	1	8	0.502	0.534	0.940	447	427	20	1141	1337	85	○	INV. EX.
43	E	1.4	99	1	0	0.499	0.537	0.930	498	476	22	1438	1495	96	○	INV. EX.
44	E	1.4	99	1	0	0.487	0.540	0.901	507	482	25	1489	1510	99	○	INV. EX.
45	E	1.4	98	2	0	0.529	0.538	0.984	488	478	10	1291	1497	86	○	INV. EX.
46	E	1.4	98	2	0	0.482	0.535	0.900	565	538	27	1669	1686	99	○	INV. EX.
47	E	1.4	99	1	0	0.525	0.534	0.982	485	477	8	1323	1498	88	○	INV. EX.
48	E	1.4	99	1	0	0.529	0.539	0.982	511	502	9	1383	1571	88	○	INV. EX.
49	E	1.4	99	1	0	0.485	0.538	0.901	564	538	26	1676	1686	99	○	INV. EX.
50	E	1.4	99	1	0	0.502	0.534	0.940	525	516	9	1414	1614	88	○	INV. EX.
51	E	1.4	99	1	0	0.509	0.536	0.950	453	444	9	1192	1390	86	○	INV. EX.
52	E	1.4	100	0	0	0.518	0.539	0.960	525	516	9	1394	1616	86	○	INV. EX.
53	E	1.4	99	1	0	0.502	0.533	0.940	526	517	9	1425	1620	88	○	INV. EX.
54	E	1.4	98	2	0	0.508	0.535	0.949	530	520	10	1405	1633	86	○	INV. EX.
55	E	1.4	100	0	0	0.505	0.537	0.939	454	431	23	1311	1352	97	○	INV. EX.
56	E	1.4	100	0	0	0.518	0.540	0.960	546	522	24	1601	1637	98	○	INV. EX.
57	E	1.4	98	2	0	0.504	0.536	0.941	486	478	8	1304	1500	87	○	INV. EX.

(continued)

No.	Steels	Sheet thick- ness (mm)	Tempered martensite (%)	Retained austenite (%)	Total of ferrite and bainitic ferrite (%)	KAM(S) (°)	KAM(C) (°)	KAM(S) /KAM (C)	Hv(Q)	Hv(S)	Hv(Q)-Hv (S)	YS (MPa)	TS (MPa)	YR (%)	Range of ap- propriate clearances not leading to de- layed fracture	Remarks
58	F	1.2	99	1	0	0.505	0.537	0.939	502	481	21	1439	1508	95	O	INV. EX.
59	G	1.2	100	0	0	0.510	0.537	0.950	443	425	18	1239	1332	93	O	INV. EX.
60	H	1.2	99	1	0	0.510	0.531	0.960	414	398	16	1141	1248	91	⊙	COMP. EX.
61	I	1.2	99	1	0	0.506	0.539	0.940	604	584	20	1731	1830	95	○	INV. EX.
62	J	1.2	100	0	0	0.507	0.534	0.949	595	576	19	1692	1804	94	×	COMP. EX.
63	K	1.2	99	1	0	0.498	0.535	0.930	460	442	18	1289	1386	93	O	INV. EX.
64	L	1.2	96	4	0	0.510	0.537	0.950	514	495	19	1327	1551	86	O	INV. EX.
65	M	1.2	94	6	0	0.505	0.537	0.941	544	532	12	1365	1665	82	⊙	COMP. EX.
66	N	1.2	91	0	9	0.510	0.537	0.950	462	446	16	1216	1397	87	O	INV. EX.
67	O	1.6	85	4	11	0.517	0.538	0.960	362	344	18	907	1077	84	⊙	COMP. EX.
68	P	1.6	98	2	0	0.504	0.536	0.941	544	528	16	1511	1653	91	○	INV. EX.
69	Q	1.6	98	2	0	0.502	0.534	0.940	504	483	21	1447	1517	95	×	COMP. EX.
70	R	1.6	99	1	0	0.506	0.538	0.939	503	481	22	1452	1509	96	○	INV. EX.
Underlines indicate being outside of the range of the present invention.																

[Table 3-3]

No.	Steels	Sheet thick- ness (mm)	Tempered martensite (%)	Retained austenite (%)	Total of ferrite and bainitic ferrite (%)	KAM(S) (°)	KAM(C) (°)	KAM(S) /KAM (C)	Hv(Q)	Hv(S)	Hv(Q)-Hv (S)	YS (MPa)	TS (MPa)	YR (%)	Range of ap- propriate clearances not leading to de- layed fracture	Remarks
71	<u>S</u>	1.6	98	2	0	0.497	0.534	0.930	525	509	16	1460	1597	91	×	COMP. EX.
72	<u>T</u>	1.6	98	2	0	0.510	0.537	0.950	508	491	17	1420	1540	92	○	INV. EX.
73	<u>U</u>	1.6	99	1	0	0.498	0.536	0.930	529	511	18	1490	1602	93	×	COMP. EX.
74	<u>V</u>	1.6	90	1	9	0.514	0.536	0.960	445	423	22	1178	1324	89	⊙	INV. EX.
75	<u>W</u>	1.4	88	2	10	0.504	0.536	0.941	436	416	20	1044	1305	80	⊙	COMP. EX.
76	<u>X</u>	1.4	99	1	0	0.512	0.533	0.960	556	544	12	1502	1703	88	⊙	INV. EX.
77	<u>Y</u>								The slab fractured during casting and the test was discontinued.							COMP. EX.
78	<u>Z</u>	1.4	98	2	0	0.514	0.536	0.960	545	533	12	1469	1666	88	○	INV. EX.
79	<u>AA</u>	1.4	98	2	0	0.514	0.536	0.960	535	523	12	1448	1642	88	×	COMP. EX.
80	<u>AB</u>	1.4	98	2	0	0.511	0.538	0.950	461	447	14	1259	1402	90	⊙	INV. EX.
81	<u>AC</u>	1.4	99	1	0	0.502	0.534	0.940	597	582	15	1651	1822	91	⊙	INV. EX.
82	<u>AD</u>								The slab fractured during casting and the test was discontinued.							COMP. EX.
83	<u>AE</u>	1.4	99	1	0	0.495	0.533	0.930	471	449	22	1352	1405	96	⊙	INV. EX.
84	<u>AF</u>	1.4	100	0	0	0.512	0.539	0.950	607	588	19	1732	1846	94	⊙	INV. EX.
85	<u>AG</u>								The slab fractured during casting and the test was discontinued.							COMP. EX.
86	<u>AH</u>	1.4	99	1	0	0.507	0.540	0.940	484	466	18	1357	1459	93	⊙	INV. EX.
87	<u>AI</u>	1.4	99	1	0	0.514	0.541	0.950	606	587	19	1727	1841	94	⊙	INV. EX.
88	<u>AJ</u>								The slab fractured during casting and the test was discontinued.							COMP. EX.
89	<u>AK</u>	1.4	100	0	0	0.498	0.536	0.930	497	475	22	1434	1491	96	○	INV. EX.
90	<u>AL</u>	1.4	100	0	0	0.502	0.533	0.940	503	484	19	1424	1518	94	⊙	INV. EX.
91	<u>AM</u>								The slab fractured during casting and the test was discontinued.							COMP. EX.
92	<u>AN</u>	1.4	99	1	0	0.502	0.533	0.940	540	523	17	1508	1636	92	⊙	INV. EX.

(continued)

No.	Steels	Sheet thickness (mm)	Tempered martensite (%)	Retained austenite (%)	Total of ferrite and bainitic ferrite (%)	KAM(S) (°)	KAM(C) (°)	KAM(S)/KAM (C)	Hv(Q)	Hv(S)	Hv(Q)-Hv (S)	YS (MPa)	TS (MPa)	YR (%)	Range of appropriate clearances not leading to delayed fracture	Remarks
93	AO	1.4	99	1	0	0.505	0.537	0.941	527	510	17	1472	1597	92	⊙	INV. EX.
94	AP	1.4	98	2	0	0.506	0.539	0.940	506	484	22	1456	1513	96	⊙	INV. EX.
95	AQ	1.4	98	2	0	0.511	0.538	0.950	553	540	13	1505	1691	89	⊙	INV. EX.
96	AR	1.4	99	1	0	0.506	0.538	0.939	557	543	14	1526	1699	90	⊙	INV. EX.
97	AS	1.4	99	1	0	0.497	0.534	0.930	524	502	22	1512	1572	96	⊙	INV. EX.
98	AT	1.4	100	0	0	0.506	0.539	0.940	562	548	14	1543	1718	90	⊙	INV. EX.
99	AU	1.4	98	2	0	0.503	0.535	0.941	521	502	19	1475	1573	94	⊙	INV. EX.
100	AV	1.4	98	2	0	0.504	0.536	0.941	500	480	20	1425	1506	95	⊙	INV. EX.
101	AW	1.4	99	1	0	0.504	0.536	0.941	505	484	21	1443	1513	95	⊙	INV. EX.
102	AX	1.4	98	2	0	0.509	0.536	0.950	526	507	19	1490	1589	94	⊙	INV. EX.
103	AY	0.8	100	0	0	0.506	0.533	0.949	470	453	17	1306	1416	92	⊙	INV. EX.
104	AZ	2.0	98	2	0	0.515	0.537	0.960	592	580	12	1606	1821	88	⊙	INV. EX.
Underlines indicate being outside of the range of the present invention.																

Claims

1. A high strength steel sheet comprising a microstructure having a chemical composition comprising, by mass%:

C: 0.15% or more and 0.45% or less,
Si: 0.10% or more and 2.00% or less,
Mn: 0.5% or more and 3.5% or less,
P: 0.100% or less,
S: 0.0200% or less,
Al: 0.010% or more and 1.000% or less,
N: 0.0100% or less, and
H: 0.0020% or less,
the balance being Fe and incidental impurities;
the microstructure being such that:

the area fraction of tempered martensite is 85% or more,
the volume fraction of retained austenite is less than 50, and
the area fraction of the total of ferrite and bainitic ferrite is 10% or less;
the microstructure satisfying formulas (1) and (2) defined below:

$$KAM(S)/KAM(C) < 1.00 \dots\dots(1)$$

wherein KAM (S) is a KAM (Kernel average misorientation) value of a superficial portion of the steel sheet,
and KAM (C) is a KAM value of a central portion of the steel sheet,

$$Hv(Q) - Hv(S) \geq 8 \dots\dots(2)$$

wherein Hv (Q) indicates the hardness of a portion at 1/4 sheet thickness and Hv (S) indicates the hardness of a superficial portion of the steel sheet.

2. The high strength steel sheet according to claim 1, wherein the chemical composition further comprises one, or two or more elements selected from, by mass%:

Ti: 0.100% or less,
B: 0.0100% or less,
Nb: 0.100% or less,
Cu: 1.00% or less,
Cr: 1.00% or less,
V: 0.100% or less,
Mo: 0.500% or less,
Ni: 0.50% or less,
Sb: 0.200% or less,
Sn: 0.200% or less,
As: 0.100% or less,
Ta: 0.100% or less,
Ca: 0.0200% or less,
Mg: 0.0200% or less,
Zn: 0.020% or less,
Co: 0.020% or less,
Zr: 0.020% or less, and
REM: 0.0200% or less.

3. The high strength steel sheet according to claim 1 or 2, which has a coated layer on a surface of the steel sheet.

4. A method for manufacturing a high strength steel sheet described in claim 1 or 2, the method comprising:

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providing a cold rolled steel sheet produced by subjecting a steel slab to hot rolling, pickling, and cold rolling; annealing the steel sheet under conditions where:

a temperature T1 is 850°C or above and 1000°C or below and
a holding time t1 at T1 is 10 seconds or more and 1000 seconds or less;
cooling the steel sheet to 100°C or below;
starting working at an elapsed time t2 of 1000 seconds or less from the time when the temperature reaches 100°C,
the working being performed under conditions where:

a working start temperature T2 is 80°C or below and
an equivalent plastic strain is 0.10% or more and 5.00% or less;
tempering the steel sheet under conditions where:

a temperature T3 is 100°C or above and 400°C or below and
a holding time t3 at T3 is 1.0 second or more and 1000.0 seconds or less; and
cooling the steel sheet under conditions where a cooling rate θ_1 from T3 to 80°C is 100°C/sec or less.

5. The method for manufacturing a high strength steel sheet according to claim 4, wherein the working before the tempering is performed under conditions where strain is applied by two or more separate working operations, and the total of the equivalent plastic strains applied in the working operations is 0.10% or more.
6. The method for manufacturing a high strength steel sheet according to claim 4 or 5, further comprising performing coating treatment during the annealing or after the annealing.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2022/020892

A. CLASSIFICATION OF SUBJECT MATTER

C21D 9/46(2006.01)i; **C22C 38/00**(2006.01)i; **C22C 38/06**(2006.01)i; **C22C 38/60**(2006.01)i
 FI: C22C38/00 301S; C22C38/00 301T; C22C38/06; C22C38/60; C21D9/46 G; C21D9/46 J

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C21D9/46; C22C38/00; C22C38/06; C22C38/60

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2022
 Registered utility model specifications of Japan 1996-2022
 Published registered utility model applications of Japan 1994-2022

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	WO 2016/129548 A1 (KABUSHIKI KAISHA KOBE SEIKO SHO) 18 August 2016 (2016-08-18)	1-6
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☐ Further documents are listed in the continuation of Box C.
 ☒ See patent family annex.

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"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
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"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

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Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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